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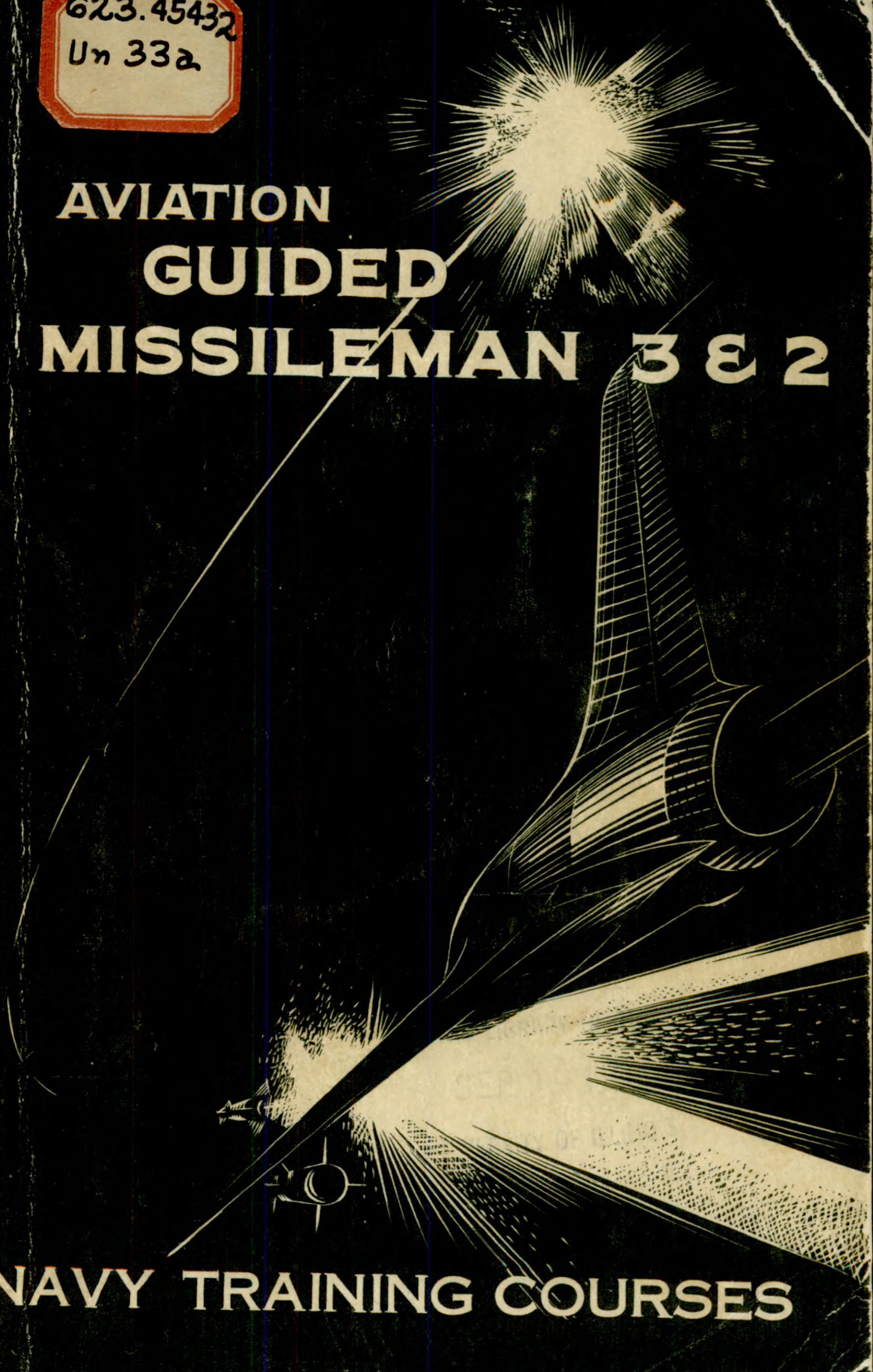
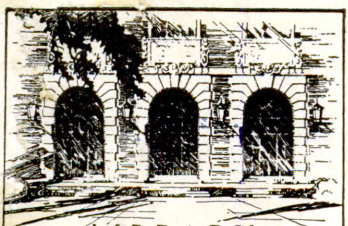
AVIATION GUIDED MISSILEMAN 3 & 2



NAVY TRAINING COURSES



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AVIATION

GUIDED MISSILEMAN 3 & 2

Prepared by

BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSES

NAVPERS 10379

UNITED STATES

GOVERNMENT PRINTING OFFICE

WASHINGTON : 1958

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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PREFACE

This course was prepared to serve as an aid for enlisted men of the U. S. Navy and the U. S. Naval Reserve who are studying for advancement to the rates of Aviation Guided Missileman 3 or 2. Combined with the necessary practical experience and a thorough study of the basic Navy Training Courses, the information contained in this volume will assist the reader in preparing for the advancement in rating examinations. The courses containing the background material required in the study of *GF 3 and 2* are *Basic Hand Tool Skills*, NavPers 10085; *Basic Electricity*, NavPers 10086; *Basic Electronics*, NavPers 10087; and *Basic Hydraulics*, NavPers 16193. The essential information provided by these texts is indicated by references appearing in appropriate parts of the chapters which comprise this course.

As one of the Navy Training Courses, this book was written by the U. S. Navy Training Publications Center, Memphis, Tennessee. Credit is given the Naval Air Weapons Systems School, Jacksonville, Florida, for supplying valuable technical information and for preparing the end-of-chapter questions which thoroughly review the materials contained in each chapter.

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READING LIST

NAVY TRAINING COURSES

Basic Hand Tool Skills, NavPers 10085

Basic Electricity, NavPers 10086

Basic Electronics, NavPers 10087

Basic Hydraulics, NavPers 16193

Blueprint Reading and Sketching, NavPers 10077–A

USAFI TEXTS

United States Armed Forces Institute (USAFI) courses for additional reading and study are available through your Information and Education Officer.* A partial list of those courses applicable to your rate follows:

Correspondence

Number	Title
CC 290	*Physics I*
CC 291	*Physics II*
CB 781	*Fundamentals of Electricity*

Self-Teaching

MC 290	*Physics I*
MC 291	*Physics II*
MB 781	*Fundamentals of Electricity*

*"Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more, regardless of the time specified in the active duty orders."

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ACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS*	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7A
SERVICE	4 mos. service—or completion of recruit training.	6 mos. as E–2 or 8 mos. total service.	6 mos. as E–3 or 14 mos. total service.	12 mos. as E–4.	12 mos. as E–5; total service at least 36 mos.	36 mos. as E–6.
SCHOOL	Recruit Training.		Class A for PR3, PRS3.		Class B for MN1.	Class B for AGCA, MNCA, MUCA.
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.			
PRACTICAL FACTORS	Locally prepared check-offs.	Records of Practical Factors, NavPers 760, must be completed for E–3 and all PO advancements.				
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.			
EXAMINATIONS	Locally prepared tests.		Service-wide examinations required for all PO advancements.			
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Required for E–3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed.				
AUTHORIZATION	Commanding Officer		U. S. Naval Examining Center			BuPers
	TARS are advanced to fill vacancies and must be approved by district commandants or CNARESTRA.					

*Recommendation of petty officers, officers and approval by commanding officer required for all advancements.

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INACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS*		E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7A
	FOR THESE DRILLS PER YEAR						
TOTAL TIME IN GRADE	24 OR 48 12 NON-DRILLING	9 mos. 9 mos. 12 mos.	9 mos. 15 mos. 24 mos.	15 mos. 21 mos. 24 mos.	18 mos. 24 mos. 36 mos.	24 mos. 36 mos. 48 mos.	36 mos. 42 mos. 48 mos.
DRILLS ATTENDED IN GRADE#	48 24 12	27 16 8	27 16 13	45 27 18	54 32 20	72 42 32	108 64 38
TOTAL TRAINING DUTY IN GRADE#	24 OR 48 12 NON-DRILLING	14 days 14 days None	14 days 14 days None	14 days 14 days [illegible] days	14 days 28 days [illegible] days	28 days 42 days [illegible] days	42 days 42 days 28 days
PERFORMANCE TESTS				Specific ratings must complete applicable performance tests before taking examination.			
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)		Record of Practical Factors, NavPers 1316, must be completed for all advancements.					
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Completion of applicable course or courses must be entered in service record.					
EXAMINATION		Standard exams are used where available, otherwise locally prepared exams are used.					
AUTHORIZATION		District commandant or CNARESTRA					BuPers

*Recommendation of petty officers, officers and approval by commanding officer required for all advancements.

#Active duty periods may be substituted for drills and training duty.

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AVIATION GUIDED MISSILEMAN

3 & 2

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CHAPTER 1

GUIDED MISSILES AND THE GF RATING

The guided missile, like many other weapons, extends the power of man's muscles by enabling him to destroy his enemy at a distance. But unlike any other of man's weapons, it is sharper than his senses when seeking the enemy, and quicker than his mind when deciding how to get to him. These highly desirable functions cause the average guided missile to be a complicated device. A GUIDED MISSILE is defined as an unmanned vehicle moving above the earth's surface, whose trajectory or flight path is capable of being altered by a mechanism within the vehicle.

This definition is broad enough to include many possible variations in design and tactical applications. The operation of guided missiles involves the fields of aerodynamics, combustion, propellants, radio-wave propagation, telemetering, proximity fuzes, and shaped charges. Effective use of the guided missile as a part of a weapon system requires qualified personnel for its handling and use.

A single missile system may contain a combination of an aircraft, a radar, and a computer. Some missiles may combine these into a single, small airframe along with a rocket motor. Because of the complexity of guided missiles, the service and repair of them will require specially trained personnel with above average ability.

THE AVIATION GUIDED MISSILEMAN

Duties and Responsibilities

Aviation Guided Missilemen handle, maintain, and repair air-launched guided missiles. Their routine duties are both military and professional. The military duties are similar

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to those in other Navy ratings; the professional duties are determined largely by the nature and characteristics of the missiles with which the rating is concerned.

Air-launched guided missiles, whether in an air-to-air, air-to-surface, or an air-to-underwater version, are complex and intricate devices. Fired from fighters or from interceptor aircraft, typical missiles fly at supersonic speeds. They are guided to the target by electronic systems such as radar or radio or by detectors of infrared radiation. The missiles are controlled in flight by complex systems containing gyroscopes; electrical systems; and electronic, hydraulic, and pneumatic devices. They are usually propelled by rocket motors or by some other form of jet propulsion; and they carry explosive warheads and often proximity fuzes. In view of the many systems which are coordinated in the tactical guided missile, it is necessary that the technicians who handle and maintain the weapon be highly trained specialists. Their work demands wide ranges of technical knowledge in several hitherto unrelated fields; and their routine duties involve many specialized skills.

The GF rating (like all other Navy ratings) is a group of jobs which require essentially the same aptitudes, training, experience, skills, and abilities. In these jobs, Aviation Guided Missilemen work with all the internal components of air-launched guided missiles except propulsion systems and ordnance devices. They employ and service many kinds of test instruments and also train other missilemen in the duties of the rating. They supervise missile handling and maintenance operations and perform the clerical and administrative duties required in these operations.

As in other Navy ratings, that of Aviation Guided Missilemen contains four rates: GF3, GF2, GF1, and GFC. The missilemen's rate indicates his pay grade and also the level of his aptitude, experience, knowledge, skill, and responsibility. Advancement in the rating is dependent on meeting certain military and professional requirements which are listed in the *Manual of Qualifications for Advancement in Rating*, NavPers 18068 (Revised). This manual is revised periodically as changes are made in the rating structure.

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The professional qualifications for GF3 and GF2 form the basis of this text, which is intended as a study aid for personnel preparing for advancement to these rates. These qualifications, together with those required for advancement to GF1 and GFC, can be found in appendix V of this course. The qualifications listed in appendix V are current through change number 10; and prior to the rating examination, the candidate for advancement must consult a revised "quals" manual for the latest requirements for his rate.

The nature of the duties of the GF and the type of tasks performed by him are indicated by the Navy enlisted classification code number assigned him. Aviation Guided Missilemen are given code numbers ranging from GF 7800 to GF 7899. The code number highlights the proficiencies and specialties which the man acquires during the course of his Navy career. For example, the GF's code number indicates the specific air-launched missile with which he is experienced.

An important part of the professional knowledge required is that which pertains to safety. The missileman is required to know the authorized methods of resuscitating victims of electric shock and of treating electrical burns. He must know and observe the safety precautions authorized when working near high voltages, and must understand the hazards present in electrical and electronic equipment. He is required to know and to observe safety measures relating to ordnance devices such as rocket motors, high explosive warheads, fuzes, and igniters. Much of his work is done near aircraft; hence he must understand and practice the precautions appropriate for this type of work as well as those pertaining to jet engines and various mechanical devices. In addition, he is expected to be familiar with the hazards of hydraulic and pneumatic systems and to use authorized safety measures when working with them.

The clerical duties of the GF3, involve the preparation of various records and reports which are required in missile activities. These duties include maintaining missile logs, recording test data, keeping equipment histories, and the

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preparation of failure reports, job orders, and work requisitions.

Missile logs.—Each missile delivered by the manufacturer is accompanied by a logbook which is used to keep an accurate history of the weapon from the time of delivery to the time it is expended. Upon receipt of the missile the log contains entries made at the factory showing the results of the manufacturer's final system test. Before acceptance of the weapon, an inspection is made by authorized Navy personnel to verify the log entries, and subsequent entries are made to record the further history of the missile. These entries give the results of field tests, preflight checks, operating times of the component parts, equipment failures during test, and any modifications made to the missile. In the case of modifications, the corresponding entries are made in the component parts section of the log. This section contains a list of all the major units which make up the missile together with the serial number of each unit. With each replacement, an entry is made showing the serial number of the new unit and the date of its installation.

Equipment histories and failure reports.—Aviation Guided Missilemen maintain equipment histories and make failure reports which are required in routine maintenance and repair of electrical and electronic equipment such as test sets, radar installations, and radio systems. The facts relating to equipment failures are recorded on electronic equipment history cards. A card is kept for each such device or unit and accompanies it during its useful life. Each history card, when properly filled out, contains information such as the type designation and serial number of the unit, the contractor, the contract number, the date of the original installation, and the installing activity. In addition to these data, an entry is made each time a failure of the equipment occurs so that the past repair history is available at any time. The information provided by the history card is used when making reports of the failures of single parts of the unit such as tubes, resistors, and capacitors.

Reports of parts failures are made by means of standard report forms which are discussed in chapter 13 of this course.

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Parts failures in electrical equipment as well as those in electronic units are reported on this form.

Studying for Advancement in Rating

Among the essential requirements for advancement in the GF rating are demonstration of proficiency in the appropriate practical factors and successful completion of the prescribed Navy Training Course, or Courses. The first requisite is met by use of a special form; the second is accomplished under the guidance of an authorized bibliography which specifies the required courses and related publications. Consider first the use of the practical-factor record.

RECORD OF PRACTICAL FACTORS.—Since 8 February 1956, the use of the standard form NavPers 760, Record of Practical Factors, has been prescribed for all active duty personnel by BuPers Instruction 1085.38. A special form is available for each rating and consists principally of a listing of the military and professional practical-factor qualifications which are prerequisites for advancement. In addition to the pertinent factors, the form provides space for the supervising officer to date and initial the completion of each factor. It also contains a space for making minor changes in the factors and gives directions for forwarding the information from one duty station to another.

The record is kept—usually by the division officer—in a way that will facilitate the marking of the form as the practical factors are demonstrated by the trainee. When the latter is transferred, his Record of Practical Factors is signed, inserted in the correspondence side of his Enlisted Service Record, and forwarded to his next duty station. In this way, the record is kept up to date and is employed on a continuing basis as the man progresses in his rating.

The forms are obtained through regular supply channels. When ordering them, use the designator NavPers 760 with the appropriate rating abbreviation following the number. For example, NavPers 760 (GF) should be ordered for use by Aviation Guided Missilemen.

BIBLIOGRAPHY OF TRAINING COURSES AND PUBLICATIONS.—A source of essential information for those preparing for

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advancement in the GF, as well as in other ratings, is provided by the bibliography entitled *Training Publications for Advancement in Rating*, NavPers 10052. This booklet is issued annually by the Bureau of Naval Personnel. It lists Navy Training Courses and other publications required or recommended in the study for advancement in each of the various rates and ratings. The required courses are indicated in the bibliography by asterisks. Those so marked must be completed by the trainee at a given rate level before he is eligible to take the corresponding advancement examination. In addition, basic courses, general courses, and in some cases, study guides, are listed which provide valuable sources of supplementary information.

When using the bibliography, it must be realized, as indicated in the *Manual of Qualifications for Advancement in Rating*, NavPers 18068, that all higher pay grades listed in the booklet may be held responsible for the materials in the publications listed for the lower rates of that particular rating. Since in many instances, only pertinent sections of publications are specified in the *Training Publications for Advancement in Rating*, the most intelligent use of this booklet will be made by concurrent reference to the Qualifications Manual for the rating concerned. Here again, it is necessary to make certain that the latest Change of the "Quals" Manual is being utilized.

HOW TO STUDY NAVY TRAINING COURSES.—In this section a method of study is described that is recommended for use with this course, *GF 3 & 2*, as well as with other courses and publications listed in NavPers 10052. This procedure contains some of the ways that have been found most effective by trainees studying Navy Training Courses for advancement. It is outlined in the following paragraphs, which are quoted from the *Navy Training Bulletin* (June–July, 1957):

"Start by reading the preface, table of contents, and index. Then thumb through the entire book, looking at the illustrations and reading bits here and there as your eyes fall on something interesting. This browsing will show you how the book is organized and the subject matter it covers.

"Next, preread the entire course. Do this to learn the relationship of parts and chapters to the whole of the rating covered in the course.

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Read the introductions to each chapter. Then read the headings and subheadings and finally the summary, if the chapter contains one. Ask yourself such questions as: What do I already know about this particular topic? How are these topics interrelated? What am I expected to know about this process or technique?

"Learn the qualifications for advancement in the rating (in the appendix). You are studying the NTC in order to meet these 'Quals.'

"These preliminary steps orient you and help you plan your study. They put you in a better position to draw on personal experience and to relate your past experience to the new material.

"After this preliminary work you are ready to fill in the details by intensive study of the chapters, sections, and subsections. What you can cover during a study session depends on (1) the difficulty of the material; (2) what you already know about the topic; and (3) your skill as a reader. At any rate, for each study session plan to master a predetermined unit of material: an entire chapter or a major section of a chapter.

"Use the PREREADING system with each section and paragraph. Skim the introduction, headings, first and last sentences of each paragraph, and all summarizing statements. As you preread, think up questions about the material. Write down these questions for future reference. Another useful technique is to make an outline during prereading, filling in the details later. When you have finished prereading, think about what you have learned thus far. Ask yourself such questions as: What main ideas are presented? What details must I look for?

"Next, read the entire chapter or section completely and carefully. As you read be on the lookout for the questions you have thought about or the details of your outline. Relate the part to the whole. Relate your previous knowledge and background experience to the discussion. Identify yourself with the situations, processes, and techniques; visualize yourself doing the things that are described.

"Recite what you have learned. This is the proof of understanding. Look at the questions you wrote down during prereading. Do you know the answers? Can you answer the questions in the quiz at the end of the chapter? Try to master the material you are studying before proceeding to a new portion of the text."

Guided Missilemen Billets

Billets for Aviation Guided Missilemen are established at naval depots, at air stations, in Aircraft Service Squadrons (FASRons), aboard aircraft carriers, and in fleet units such as fighter and patrol squadrons. Aviation Guided Missilemen are also assigned to training centers and to naval facilities engaged in testing and evaluating guided missiles.

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At Navy depots and air stations, GF personnel receive missiles from the manufacturer, store them, and assist in the processes of distribution to service squadrons and aircraft carriers. In these facilities, missiles are assembled and disassembled, tested, and maintained; and operations involving major overhaul and repair are conducted. In these processes, GF personnel are concerned with all components of air-launched missiles with the exception of ordnance and propulsion equipment such as rocket motors.

The FASRon and carrier guided missile units receive supplies of weapons from Navy depots or air stations and prepare them for reissue to the operational squadrons. Many maintenance checks are made on the complete weapons and their components. Missile personnel at these facilities also repair or replace faulty sections, replace defective electronic packages, and make various adjustments in each system. They make tests to determine the readiness of the missile for use, maintain and repair test equipment, and service the electrical and electronic units required in the operational use of the weapon.

GF personnel assigned to operating squadrons perform preflight checks, load missiles on the aircraft, and maintain the equipment associated with air-launched guided missiles.

In training billets, GF petty officers serve as instructors in Naval Weapons Schools in which personnel are trained in the operation and maintenance of specific guided missiles. The instructors are carefully chosen from personnel experienced in missile operations. They conduct classes in many of the phases of guided missile theory and practice, including such subjects as fundamentals of electricity and electronics, essentials of gyroscopes, missile motors, and servomechanisms. They instruct trainees in the authorized procedures for making operational and maintenance tests of specific missiles, and in the functions and operation of standard and specialized test equipment.

Guided missile units are assigned to Naval Test Centers to assist in the work of testing and evaluating new guided missiles. Personnel of these missile units receive specialized instruction in the procedures of handling, preparing, and

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maintaining new weapons and learn to service and operate the airborne and ground equipment associated with them. The development squadron to which the missile unit may be assigned also assists in determining the suitability of new missiles for introduction into the fleet, in working out procedures for training personnel in their use, and in rendering many other services to various naval activities engaged in missile test and development.

MISSION OF GUIDED MISSILES

Guided missiles are being developed to overcome the limitations of present weapons. The development of conventional weapons has reached a point where tremendous cost and effort are necessary to produce only a small improvement in their performance. The primary mission of the guided missile is to increase the range, reduce the effectiveness of enemy countermeasures, and increase the destructive effect of present weapons. Also, guided missiles can serve as counterweapons which can destroy supersonic aircraft and long-range missiles. The following examples show the limitations of several familiar weapons and the advantages of using guided missiles to supplement or replace them.

Air-to-surface guided missiles are greatly superior to conventional bombs. The aircraft dropping bombs is limited in the performance of its mission by weather, interception by enemy aircraft, antiaircraft artillery, and, in some cases, the maneuvering of the target during the fall of the bombs. By building bombers that can fly higher and faster, antiaircraft artillery and fighter interception can be evaded; but the accuracy of the bombs would be greatly reduced, and the weather would have a greater effect. By replacing the bombs with guided missiles which can be launched at greater ranges and which contain a guidance system that will home on the target regardless of weather and target maneuvers, the destructive effect can be greatly increased, and the danger of enemy countermeasures greatly reduced. The effectiveness of this type of guided missile is illustrated by the following incident which occurred during World War II in the Pacific.

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Two Navy patrol planes sighted two ships 20 miles away by radar. They went in close enough to identify them visually as Japanese destroyers and were met with heavy antiaircraft fire at a range of 8 miles. When the planes turned away and were out of range, the Japanese stopped firing. One plane then returned and launched a guided missile (named the *Bat*) from outside the antiaircraft range. The missile sped straight for the leading destroyer and blew off her bow. The other destroyer rushed to her aid, throwing futile antiaircraft fire in the direction of the attacking plane, which was out of range. The Japanese probably did not understand the true nature of the flying bomb, which struck with little or no warning after being launched from planes flying at what normally would be considered safe ranges.

Air-to-air guided missiles can greatly increase the striking range and destructive power of airplanes. The interceptor aircraft of the past has relied primarily on its speed advantage to maneuver into position where its short-range weapons were effective. Against modern jet bombers or missiles, interceptors lose their speed advantage, thus making them unable to maneuver into position for attack. By arming them with long-range missiles which travel at supersonic speeds, the interceptor will be capable of combating the high-speed, high-altitude weapons of modern warfare.

Surface-launched guided missiles offer many advantages over antiaircraft and bombardment artillery. Present antiaircraft guns are somewhat ineffective even against the low-speed aircraft of World War II. The supersonic guided missiles being developed are greatly superior to these weapons, and are capable of destroying modern high-speed aircraft.

At present, aircraft are used to overcome the range limitation of bombardment artillery. Aircraft, however, are hampered by enemy air superiority, antiaircraft artillery, and weather. The long ranges of guided missiles overcome this limitation, thus reducing the need of aircraft for this mission. These guided missiles can be equipped with

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guiding devices that are not affected by weather, thus making them more versatile than present weapons.

CLASSIFICATION OF GUIDED MISSILES

Guided missiles are being developed rapidly by the Armed Forces to fulfill many missions such as antiaircraft defense from ground and air; long-range bombardment; submarine defense by both ships and aircraft; research; and training. To identify the various missiles a simple classification system has been used for some time by the Navy. It was also used by the Army and Air Force but has been discontinued by them for other systems. The type designation consists of symbols indicating the status, mission, missile, developing agency, design number, and modification letter of the missile. These symbols are grouped into three major parts: a basic designation, a service letter, and a model number with modification letter. An example is shown in figure 1–1.

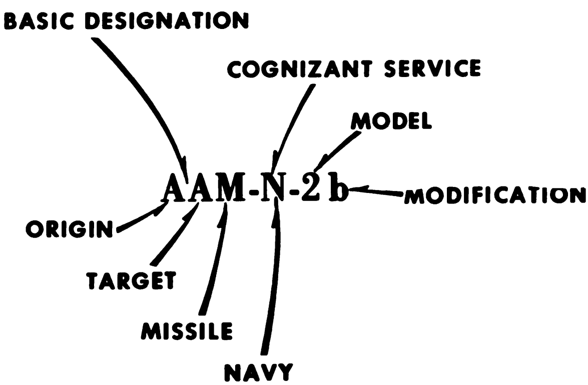

Figure 1–1.—A guided missile designation.

The basic designation indicates the mission of the missile. For missiles designed as military weapons it is a two-letter combination followed by the letter M, which indicates MISSILE. The first letter indicates the origin (launching place), and the second indicates the objective (target). The letters used are A for air, S for surface, and U for underwater. For example, an antiaircraft missile launched from

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the ground would be designated SAM, and the basic designation for an air-launched guided torpedo would be AUM. Other basic designations are:

AAM, air-to-air missile
ASM, air-to-surface missile
SSM, surface-to-surface missile
SUM, surface-to-underwater missile
UAM, underwater-to-air missile
USM, underwater-to-surface missile

The second major part of the type designation is a service letter which formerly indicated the agency responsible for the development of the missile. At present the only service letter used is N, which indicates Navy. It is separated from the other parts of the designation by dashes.

The Navy may design several missiles for the same mission. To indicate each design, a model number is placed after the service letter in the type designation. For example, SAM–N–3 and SAM–N–5 would be two surface-to-air missiles developed by the Navy. Model 3 might be a short-range antiaircraft missile, and model 5 a long-range antiaircraft weapon. When a particular missile is modified, a lowercase letter, beginning with *a* for the first modification, is added to the model number. For example, SAM–N–3b is the second modification of the SAM–N–3 missile. The model number with modification letter is the third major part of the type designation.

When the development of a guided missile is first started, an X is placed in front of the basic designation to indicate that it is an experimental missile; for example, XSAM–N–2. When the missile has been developed, it is given extensive tests by the service for which it was designed. During the service test period the X is replaced by the service test letter, Y. After the missile has undergone successful service tests and has become a standard weapon, the Y is dropped. If a missile becomes obsolete, the prefix letter Z is assigned. When a missile is designed for training missile personnel, the basic designation is prefixed by the letter T; for example, TAAM–N–5.

Some missiles are designed only for testing or research.

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A special basic designation TV (test vehicle), is used for these. A letter preceding the basic designation indicates the type of test for which the missile is used. Some of the tests are: control system; propulsion system; and launching; designated by the letters C, P, and L, respectively. For example, CTV–N–2a is the designation for control test vehicle, Navy, second model, first modification. When a test vehicle is used for research, such as high-altitude measurements, the basic designation is preceded by the letter R.

Popular names, such as *Sparrow*, *Regulus*, *Terrier*, *Petrel*, and *Loon*, are first given to a missile when it is in the development stage.

DEVELOPMENT OF GUIDED MISSILES FOR WARFARE

Origin

The evolution of the guided missile as a military weapon began with rockets, which were first used by the Chinese against the Tartars in the Battle of Pien King in 1232. The British employed military rockets against the French in 1806, and again during the War of 1812. Great advances in the science of rocketry were made in the first part of the 20th century by an American, Dr. R. H. Goddard. One of his most notable achievements was the development of the mathematical theory of rocket propulsion and rocket flight, on which military and experimental calculations are now based.

The study of the rocket, the forerunner of guided missiles, brought about the realization that some form of guidance would be necessary if the potentialities of high speed and great range were to be used profitably. Even before the achievements of Dr. Goddard, steps had been taken to develop guided missiles.

The use of airplanes as military weapons during World War I brought about the idea of remotely-controlled aircraft that could be pilotless. An American, Charles F. Kettering, designed a pilotless aerial torpedo which, although not remotely controlled, made a successful stabilized flight in October 1919. The first such aircraft was a radio-con-

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trolled model airplane which was successfully flown about 1935. Drone (OQ and PQ) planes were the first remotely-controlled vehicles used by our Army and Navy.

German Development

The Germans accepted the airborne guided missile as a military weapon about ten years before World War II. During World War I they considered the possibility of improving bombing accuracy by using electric signals sent over fine wire to guide a bomb as it fell. In 1933 the German Army initiated a study of rockets and guided missiles; and in 1936 a research and development center was established at Peenemunde. A great many scientists were assigned to guided missile projects with the intention of producing a complete series of guided missiles to cover every field of defensive and offensive warfare.

Contracts were made with private firms, German universities, and technical schools for the development of rockets and guided missiles. Theoretical studies were undertaken, and considerable development of surface-to-surface weapons was completed. Guiding systems for surface-to-air weapons were not very successful, and in 1943 the 48 different antiaircraft missiles under development were consolidated into 12 weapons. The Germans attempted to carry these through to immediate development for opertional use. At the end of World War II they were still working frantically to produce a surface-to-air guided missile with a speed of 300 miles per hour, and a ceiling of about 50,000 feet for use against Allied bombers.

German scientists were more successful in the development of surface-to-surface and air-to-surface missiles. The launching of a radio-controlled glide bomb, the HS–293 shown in figure 1–2, began the long-awaited and much-dreaded era of guided missile warfare. In August 1943 a British convoy was steaming through the Bay of Biscay on the alert for enemy submarines and airplanes. The lookouts on one of the ships saw what appeared to be a small bomber come out of a turn and head directly toward the ship at an incredible speed. Antiaircraft guns attempted to shoot it

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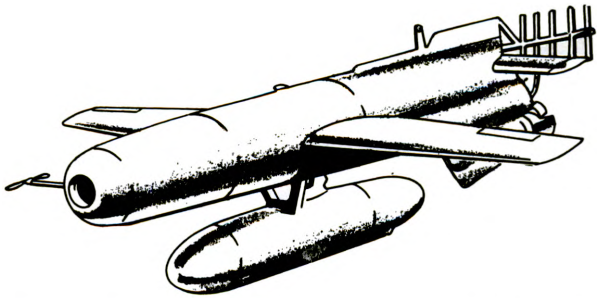

Figure 1–2.—German HS–293 radio-controlled glide bomb.

down, but because of its small size and great speed they did not stop it. As it approached the ship, it did not drop a bomb and pull out of the dive in the familiar dive-bomber technique, but continued on its course until it struck the ship.

Here, for the first time in the history of warfare, a radio-controlled guided missile, produced in sufficient quantities to affect the course of the war, was used. Although devices that might be classified as guided missiles had been used previously, they were primarily makeshift weapons such as remotely-controlled airplanes.

Another air-to-surface missile of the same type was the FX–1400 bomb, shown in figure 1–3. It was a standard bomb fitted with a specially designed tail to receive the radio

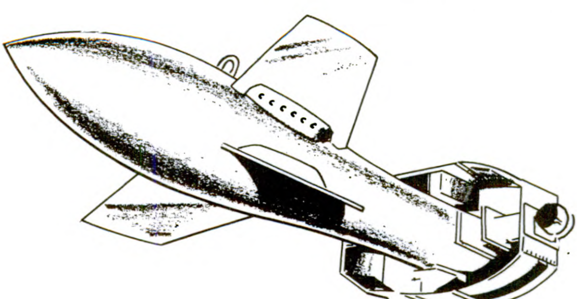

Figure 1–3.—German FX–1400 radio-controlled bomb.

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signals and control the aim of the bomb. Just why the Germans did not exploit and use more radio-controlled missiles is not known. However, they probably feared that these weapons could be easily countermeasured. This fear led them to develop mechanical control systems that were preset before launching. Such control systems were used almost exclusively in their long-range missiles.

Allied intelligence revealed as early as 1943 that the Germans had developed long-range guided missiles at Peenemunde. The first of these weapons, the V-1 shown in figure 1-4, was launched against England from the Pas de Calais area of France in June 1944. The buzz bombs (V-1's) were launched from the ground and powered by a pulse-jet motor at a range of about 125 miles.

During the next three months over 8,000 V-1 missiles were launched against England. The Allies overran the Pas de Calais launching area in September 1944, thus ending the first phase of the V-1 attacks. The Germans, however, were making new plans for continuing guided missile warfare, and England had to pass through two more phases of V-1 attacks. The second phase, which began with the air launching of the bombs, lasted from September 1944 to January 1945. During this period 1,012 launchings were recorded. The Germans were losing air superiority and the second phase ended. The third and last phase of the V-1 attacks consisted of 158 ground launchings from Holland during March 1945

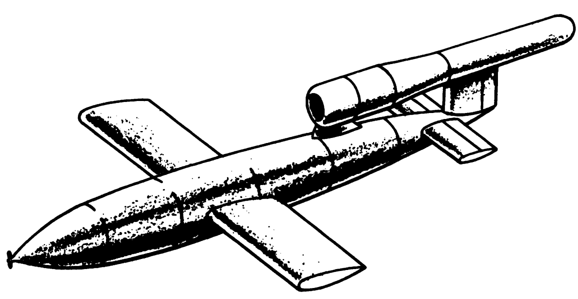

Figure 1-4.—V-1 buzz bomb.

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As the first phase of the V–1 attacks was subsiding in September 1944, the Germans introduced the V–2 long-range missile shown in figure 1–5. The Allies were not surprised, for in autumn of 1943 they received a report from Zurich that the Germans had fired 45-foot, 12-ton rockets over ranges up to 45 miles. Also in January 1944, the Allies received reports from Stockholm that a missile, similar to the one mentioned above, rose to a height of 35 miles, traveled 65 miles before crashing, and cleared a circular area 600 yards in diameter in the forest where it crashed.

The V–2 was the first long-range rocket-propelled missile operated at supersonic speed to be used against an enemy. Although the V–2 was used operationally in large numbers, it was never fully developed. Continuous experiments were made with the component parts and many changes were made to improve its performance. Of the 2,676 missiles launched during the war, 1,314 were against Antwerp after it was captured by the Allies. About 65 percent of the missiles directed at Antwerp landed within a 6-mile radius of the center of the target.

The V–2 was propelled by a liquid-rocket motor burning

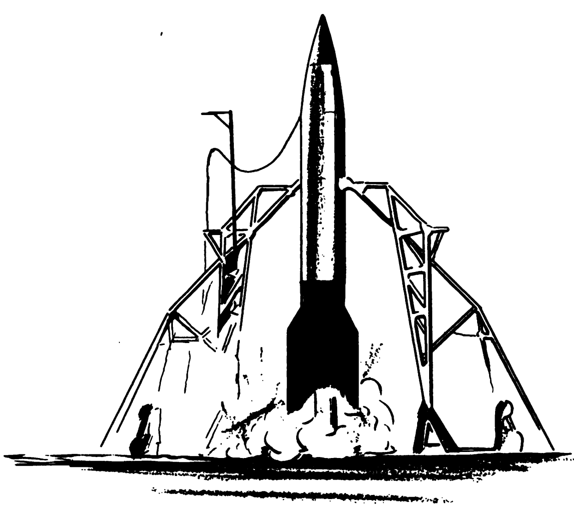

Figure 1–5.—The German V–2 missile.

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liquid oxygen and alcohol and was designed to carry a payload of 1,654 pounds from 150 to 230 miles. It was launched vertically from the ground against fixed targets of large area. After it had been in the air a few seconds, it tilted in the direction of the target. The amount of tilt during the climb period was preset according to the range of the target. At its maximum altitude of about 35 miles it had reached a speed of approximately 3,300 miles per hour. The rocket motor was turned off and the missile continued on a trajectory similar to that of an artillery shell. As it fell through the atmosphere, it was slowed down to about 1,800 miles per hour at impact. The high altitude and supersonic speed of the V–2 made it practically impossible to countermeasure. Since it was supersonic, it would hit the target before it was heard approaching.

It is believed that if the Germans had been given a relatively short extension of time, they would have succeeded in developing antiaircraft missiles that would have seriously curtailed our bomber operations, and they would have produced superior surface-to-surface assault weapons which would have made the V–2 appear as a crude experiment. In general, the Germans were no further advanced than the Allies in design and engineering, but they were much further advanced in production and experimentation. The V–2 was by far the most outstanding achievement of all types of jet-propulsion devices produced before the end of World War II.

U. S. Development

In 1941 our Armed Forces became vitally interested in the development of guided missiles. Research based on newly discovered scientific principles of radar homing, aerodynamics control of glide bombs, and pilotless aircraft had been under investigation for some time. Early success with target drones indicated the practicability of equipping them with warheads and crashing them into desired targets. This idea led to the development of special ASSAULT DRONES by the Navy Bureau of Aeronautics. The possibility of applying radar systems to glide bombs was suggested in a Navy

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Bureau of Ordnance conference, and led to the development of the *Bat* missile.

Flying *Bat* bombs, launched from Navy planes, were the first FULLY AUTOMATIC guided missiles to be used successfully in combat by any nation. A closely guarded secret of the war, this guided missile was given the code name *Bat*, which suggests the principle on which it operates. Live Bats give out a short pulse of sound and guide themselves by the echo. Similarly, the *Bat* missile was directed by radar echoes from the target.

The *Bat*, shown in figure 1–6, is a bomb mounted in a glider type of airframe, which is equippped with (1) a radar transmitter and receiver which enables it to home on the target, (2) a stabilizing unit using a gyroscope for its reference and (3) a system to move the control surfaces. It derives the power for its glide from its speed at release from the airplane and the pull of gravity.

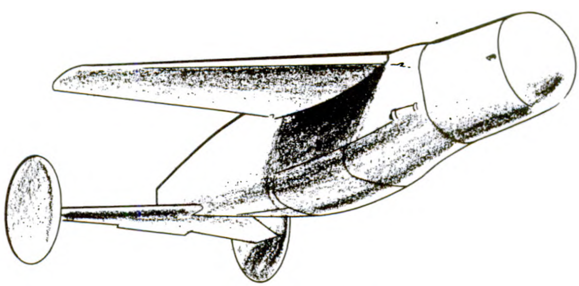

Figure 1–6.—The *Bat*.

The *Bat* was designed for use against ships, regardless of visibility, but also could be used against certain land targets. *Bat* bombs were used very effectively in World War II in destroying many tons of Japanese combat and merchant shipping.

Another important development in guided missiles during World War II was the *Azon*, shown in figure 1–7, so called because the missile was controlled in azimuth only by remote radio signals. The *Azon* was a standard 1,000-pound bomb fitted with an extended tail that carried a flare, a radio re-

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ceiver, a gyrostabilizer to prevent rolling, and rudders for steering to right or left.

During World War II *Azons* were used by the Air Force in Italy, France, and Burma. In Italy, several bridges were destroyed and the Avisio Viaduct leading to the Brenner Pass was put out of commission for a long time. In France several bridges, as well as important canal locks, were destroyed. The most effective use of *Azons* was in Burma, where, for all practical purposes, enemy transport ceased to exist in December 1944. The *Azon* crews first destroyed the bridges and then blew up the substitutes as fast as they were built.

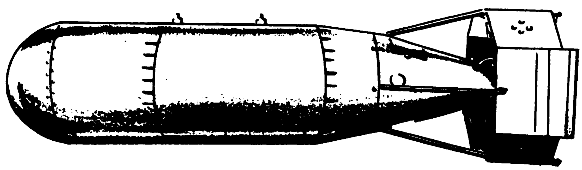

Figure 1–7.—*Azon* tail assembly mounted on a 1,000-pound bomb.

Basic research in the fields of radar and radio-controlled pilotless aircraft led to the development of the *Bat* and *Azon*. Another important field of physics which has excellent application to guided missiles is that of infrared, or heat radiation. All objects which are at temperatures above absolute zero (−273° C.) emit heat radiation. Military targets such as ships, factories, and aircraft are in general warmer than their surroundings. The presence of these targets may be detected by the heat radiation they emit. Heat radiation is similar to ordinary light except that its frequency is lower, and it cannot be seen but may be detected by devices such as the thermopile and bolometer. These devices are discussed in detail in a later chapter.

The *Felix* bomb, shown in figure 1–8, was the first guided missile which utilized the infrared radiation of the target. It was automatically guided by means of an infrared homing device located in the nose of the bomb. The *Felix* was thoroughly tested and declared reliable and adequate for operational use, but the war ended before it could be used under combat conditions. The *Felix* missile represents a very

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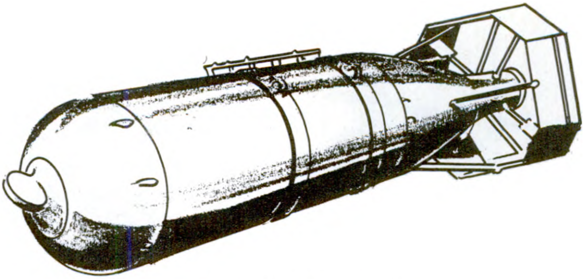

Figure 1–8.—*Felix* bomb.

important milestone in the development of present guided missiles. It opened the way to a new and different method of guidance, INFRARED HOMING.

The *Roc* missile, shown in figure 1–9, was designed to carry a radar homing device similar to the one used in the *Bat*. During the testing phase of the development program it became evident that the radar signals by which the missile was guided were not reliable at the steep glide angle at which the *Roc* was designed to fly. A search was made for another method of guidance, and the final version of the *Roc* missile combined television equipment for transmitting a picture of the target to the launching airplane and a radio-control system for guiding the missile. This was the first use of television as a method of guidance.

The *Bat*, *Azon*, *Felix*, and *Roc* missiles were bombs improved by the addition of guidance equipment. Work on jet-propelled air-to-surface guided missiles was started early in 1943 by the Navy Bureau of Aeronautics with the *Gorgon*

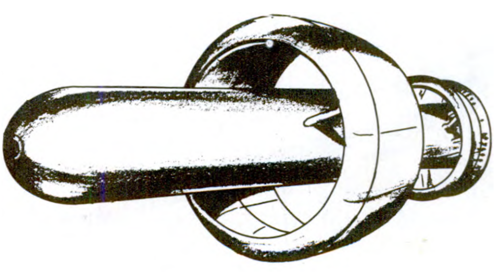

Figure 1–9.—*Roc* missile.

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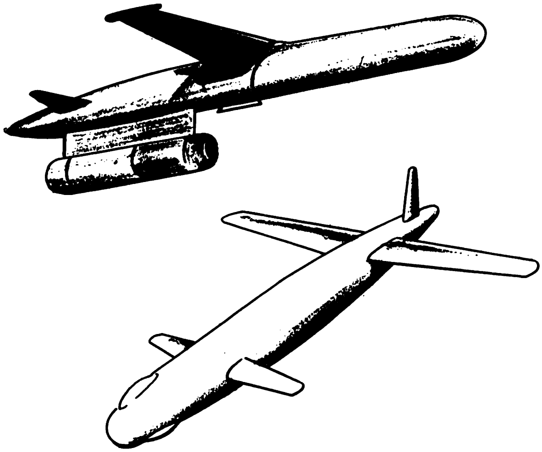

Figure 1–10.—*Gorgon* missiles.

series of missiles. Later in 1943 a rocket-boosted air-to-surface missile, the *Gargoyle*, was developed. Figure 1–10 shows two of the missiles developed in the *Gorgon* series.

In 1944, fleet losses from Japanese Kamikazes and Bakas spurred the development of ship-to-air missiles. The first missile developed in this program was the subsonic *Lark*, guided by a radar beam. The *Lark*, shown in figure 1–11, was used for training and test work in the development of guidance, launching, and handling techniques.

The *Lark* missiles were not available for use during the war, but the knowledge and experience gained in the development program were used to develop new and better missiles.

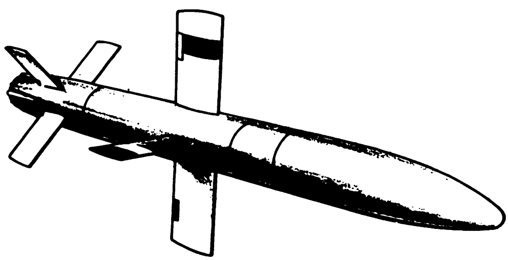

Figure 1–11.—*Lark* missile.

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The *Terrier*, shown in figure 1–12, is the first ship-launched antiaircraft missile to be adopted by the Navy for operational use. The *Terrier* is powered by a solid-propellant rocket motor, and reaches a speed twice that of sound. The *Terrier* is classified as a medium-range missile.

Modern jet fighters, with their high speed and large turning radius, have increased the range requirements of aircraft armament. Also, today's bombers are built much more rigidly, and greater destructive power is required to destroy them. These factors have greatly reduced the effectiveness of aircraft armament such as the .50 caliber machinegun and the 20-mm cannon. In an effort to increase aircraft armament, the air-to-air rocket was developed. With the great strides made in research and development of guided missiles it became feasible to guide the air-to-air rocket by such methods as radar beam-riding or radio control. Also, a rocket could be equipped with a homing device which would operate on the principle of radar, infrared, or sound. (Several of these guidance systems are discussed in later chapters.)

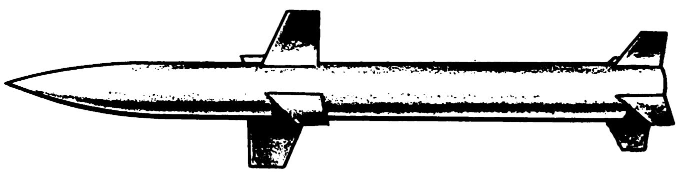

Figure 1–12.—*Terrier* missile.

The *Sparrow* is the first Navy air-to-air guided missile to become an operational weapon. A jet fighter armed with four *Sparrow* missiles is shown in figure 1–13. The *Sparrow* missile, shown in figure 1–14, is guided by a radar beam for a range of about five miles. A solid-propellant rocket motor boosts its speed to about 2.5 times the speed of sound, and one missile has enough destructive power to destroy a bomber.

Many other guided missiles have been designed during the research and experimental phases of development. Those discussed here represent significant steps in the progress of present and future weapons.

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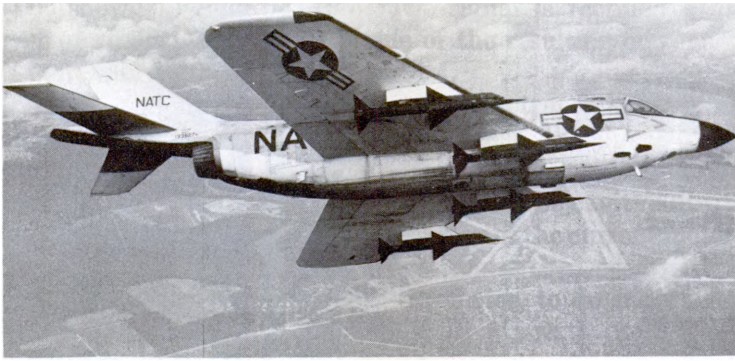

Figure 1–13.—A jet fighter armed with *Sparrow* missiles.

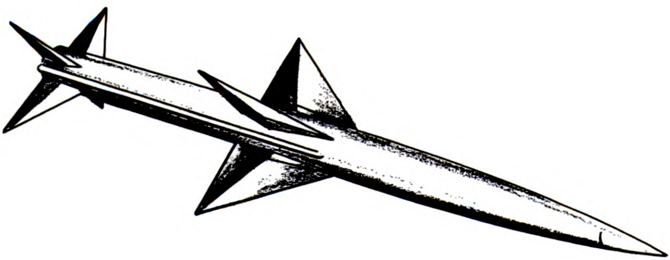

Figure 1–14.—*Sparrow* missile.

The guided missile is a new and powerful device. It is not possible at the present time to replace all weapons with guided missiles; however, certain missiles have been developed which are greatly superior to present weapons and are now being used in the fleet. These missiles are more difficult to handle, service, and maintain than conventional weapons. To make the most effective use of them the Navy has created a new rating for personnel trained to maintain air-launched guided missiles.

In this first chapter the nature of the guided missile has been introduced, its mission as a military weapon discussed, and significant steps in the history of its development have been shown. Also, the primary duties of personnel in the GF rating have been described. As pointed out in the

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discussion, most of the work of the GF concerns maintenance and repair of missiles and associated test equipment. To serve as a foundation for later discussions of the technical nature of these duties, it is first necessary to consider the basic components which make up any guided missile. The following chapter is devoted to a discussion of these basic components.

QUIZ

1. The missile designation XASM–G–2b would indicate
   a. extra, air to surface, missile, Army, second design number, Bell Aircraft
   b. experiment, air to air, missile, Army, second modification, Bell Aircraft
   c. experimental, surface to air, missile, Army, second design number
   d. experimental, air to surface, missile, Army, second design number, second modification
2. The main factors that made countermeasures ineffective against the German V–2 were
   a. countermeasure cost and position of V–2 radar antennas
   b. missile speed and position of antennas at the rear
   c. missile speed and exclusive use of preset guidance
   d. countermeasure cost and use of UHF radio control
3. Select the main advantage of guided missiles as compared with other weapons.
   a. Range and accuracy are increased.
   b. They are easier to manufacture.
   c. Foreign nations do not have them.
   d. They do not need as large a warhead.
4. Four things needed to qualify a vehicle as a guided missile are guidance, payload,
   a. propulsion, and wings
   b. booster, and airframe
   c. propulsion, and booster
   d. propulsion, and airframe

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5. The primary mission of the guided missile is to
   a. replace present weapons
   b. countermeasure long-range missiles
   c. increase range and destructive effect of present weapons
   d. act as defensive weapons

6. Interceptor aircraft will be capable of combating modern high-speed, high-altitude bombers with the aid of their
   a. speed advantage
   b. greater maneuverability
   c. larger guns
   d. long-range, supersonic missiles

7. The missile designator consists of symbols indicating status, developing agency, modification letter, design number, and
   a. manufacturer
   b. type of guidance
   c. mission
   d. type of warhead

8. The first use of the guided missile as a military weapon was by the
   a. British against the French in 17th century
   b. Germans against the British in 20th century
   c. British against the Americans in the War of 1812
   d. Americans during the Civil War

9. The weapon that launched the guided missile era was the
   a. V–1
   b. V–2
   c. HS–293
   d. FX–1400

10. The V–1 buzz bomb used a __________ for propulsion.
   a. pulse jet
   b. ram jet
   c. liquid rocket
   d. turbojet

11. The V–1 buzz bomb was a __________ missile.
   a. long-range, supersonic
   b. long-range, subsonic
   c. short-range, supersonic
   d. short-range, subsonic

12. When was the V–2 fully developed by the Germans?
   a. The autumn of 1944
   b. The autumn of 1943
   c. Never
   d. The spring of 1944

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13. The V–2's that were launched were fired against
    a. England
    b. Britain and France
    c. England and Antwerp
    d. Britain and Holland
14. The first fully automatic guided missile used in combat was the
    a. V–1
    b. V–2
    c. *Azon*
    d. *Bat*
15. The infrared homing system operates on the principle that
    a. targets emit a red light that is detectable
    b. targets are colder than their surroundings
    c. radio, radar transmissions by the enemy can be detected and tracked
    d. all objects above the temperature of absolute zero emit a detectable heat
16. The GF's code number indicates
    a. specific missile experience
    b. specific missile experience and level of technical qualification
    c. level of technical qualification
    d. whether he is a guidance technician or a propulsion and ordnance man
17. Entries in the missile log after acceptance need to be made
    a. only when the missile is fired
    b. only when a section of the missile is replaced
    c. only after a preflight check
    d. whenever something is done to the missile that will affect its history
18. The FASRon and Carrier Guided Missile Units receive their supplies of weapons from
    a. ASO
    b. manufacturer
    c. ASD
    d. Navy depots, or air stations

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CHAPTER 2

COMPONENTS OF GUIDED MISSILES

All guided missiles must contain certain components in order to perform their mission. The missile must have a body or basic structure; it must be propelled; it must be guided; and it must carry a payload. The principal structure of the missile, which houses the other components, is called the AIRFRAME. The component which moves or propels the airframe is the PROPULSION SYSTEM, or power plant. The component which makes the vehicle a true guided missile is the GUIDANCE AND CONTROL section. Further, if the missile is to perform a useful military mission, it must contain a payload consisting of a WARHEAD AND FUZES.

Various types of these components are discussed here to serve as a basis for future chapters, and many of the terms applied to guided missiles are introduced. In addition, this chapter includes a section on the functions and types of launchers, which are necessary in the operation of guided missiles.

AIRFRAMES

The airframe of a guided missile consists of the body of the weapon and the airfoils which stabilize it in flight and control its path. The missile airframe serves the same purpose as the airframe of an ordinary airplane: it carries the necessary components and determines the flight characteristics of the vehicle. But since a guided missile is essentially a one-shot weapon, the body structure suitable for it can be simpler in construction than the corresponding parts of conventional aircraft.

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The missile configuration—the shape and size of the fuselage and the shapes and locations of the wings and fins—must meet several important requirements. Among these are the following:

1. The body and airfoils must be aerodynamically suitable for the speed at which the missile is to fly.

2. The entire airframe must be light in weight and sufficiently strong and rigid to withstand the enormous shock loads, vibrations, and accelerations encountered in high-speed flight.

3. The airframe must be easy to assemble and to disassemble, and it must be designed so that the inner components are readily available for removal and repair. The major components should be mounted so that they form independent units, and the missile body should contain adequate room to permit slack in the electrical cables and harnesses so that the inner sections can be removed easily during field maintenance and repair operations.

4. It is desirable that the sections of the airframe be simple in structure and easily fabricated. It is also important that the sections be constructed of material which is easy to work and which is noncritical as to supply.

In most missiles the main body is a slender, cylindrical structure. Several types of nose sections are employed. If the weapon is intended for speeds exceeding that of sound, the forward section usually has a pointed-arch profile in which the sides taper in lines called "ogive" curves. In missiles which fly at lesser speeds, the nose is frequently less sharp or is even blunt. In some, the forward end is covered by a rounded radome; in others, the nose section contains the opening which forms one end of the duct required for the jet power system.

Typical airframes contain a main body which terminates in a flat base. When the contour is slightly streamlined at the rear, the missile is said to be "boattailed." Attached to the body are one or more sets of airfoils, which provide lift in some cases, and which control the flight path and increase the stability. The basic types of design which are employed in missile airframes are distinguished principally

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by the location of the control surfaces with respect to the missile body. These types are the CANARD, the WING-CONTROL, and the TAIL-CONTROL designs.

For canard airframes, small control surfaces are employed which are placed forward of the center of gravity, the point at which the total mass of the body can be considered as being concentrated. Fixed fins, larger than the control surfaces, are mounted on the tail section to increase flight stability.

In the wing-control design, the control surfaces are mounted at or near the center of gravity. Larger than in the canard arrangement, the controlling surfaces also provide considerable lift; and fixed fins are mounted at the tail section of the missile body. In the tail-control configuration, the control surfaces are placed at the rear of the airframe. If wings are included, they are mounted amidships and contribute lifting force but do not control the flight path.

The fuselages of many of the larger guided missiles, such as the surface-to-surface weapons, resemble those of modern aircraft in construction, being based on the SEMIMONOCOQUE structure which is widely used in conventional airframes. The semimonocoque fuselage (the word "monocoque" means "one shell") consists of a metal skin or shell which is internally braced. The strength of the body is provided mainly by the shell, which is reinforced by inner bulkheads, called FRAMES, and longitudinal braces, called STRINGERS.

In air-launched missiles—particularly in the air-to-air weapons—the missile body is generally made up of several sections. Each section is a cylindrical shell which is machined from metal tubing rather than a built-up structure with internal bracing. Each body shell contains one of the essential units or components of the missile, such as the propulsion system, the electronic control equipment, the warhead, or the fuze assembly.

Sectionalized construction has the advantage of strength with simplicity and also provides ease in replacement and repair of the components since the shells are removable as separate units. The sections are joined by various types of connections which can be easily made or unmade. An example is the so-called BREECH-LOCK connection, in which

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the shells contain machined, interrupted threads, allowing the body sections to be joined by making an eighth of a turn. Access ports are usually provided in the walls through which adjustments of the inner components can be made prior to loading the missile on the aircraft.

The body sections, the fins, and the wings of air-launched missiles are constructed from materials which have high ratios of strength to weight in order to insure the necessary strength and rigidity. The airfoils must be thin structures which are required for supersonic flight; and in order to secure the necessary rigidity, these parts are generally machined from solid blocks of metal. Materials frequently used are alloys of aluminum, and magnesium.

In the assembled missile, many of the component sections are joined by electrical cables. The connections are made by means of harnesses which run through TUNNEL assemblies. In some of the sections the tunnels are routed internally; and in others, for example, those which house rocket motors or some part of the propulsion system, the tunnels are faired onto the outer skin of the body section.

One or more special connectors called UMBILICAL PLUGS are secured to the missile body flush with the skin. These plugs mate with connectors through which electrical connections are made between the missile components and the launching equipment.

PROPULSION SYSTEMS

In order to be an effective military weapon, a guided missile must move at a high speed. It must do so in order to better its chances of intercepting enemy missiles or aircraft when used defensively, and to decrease its chances of being intercepted when used offensively. Missiles are moved in a desired direction and at a desired speed in response to applied forces. These forces are produced by the propulsion system (power plant). The purpose of this section is to discuss briefly the means available for propelling guided missiles.

One method of obtaining motion in a guided missile is to raise it above the earth's surface and allow it to fall freely

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toward the earth. In this case, the motive power is supplied by the gravitational pull of the earth. (A freely falling body accelerates at the rate of approximately 32 feet per second per second.) When dropped within the earth's atmosphere, it accelerates until such time as its aerodynamic drag balances the gravitational force pulling it toward the earth. The body then has reached its terminal or maximum speed, which, although it may be several hundred miles per hour, is still insufficient for many missile applications. If controlled, a missile of this nature is a CONTROLLED GRAVITY BOMB. The control of such a missile is obtained by the movement of aerodynamic surfaces (ailerons and rudders) in response to control signals. Missiles of this type, such as the *Bat* and the *Azon*, have been used with considerable effectiveness. These controlled gravity bombs have many limitations; and other sources of motive power are used more extensively in guided missiles.

In order to meet the requirement that some guided missiles move with high speeds, it is necessary to propel them in some other manner. This requirement has been met by the use of jet-propulsion systems. These systems are essentially high-speed power plants and, therefore, they are very suitable for guided missile use. The following section is a discussion of the general principles of jet propulsion, and the types of thermal-jet motors used in guided missiles.

Principles of Jet Propulsion

Jet-propulsion systems are referred to as REACTION MOTORS because they operate on the reaction principle. This principle was stated first in Sir Isaac Newton's third law of motion, which says that for every action there is an equal and opposite reaction. This means that if a man pushing a car exerts a force of 150 pounds on the car, the car exerts an equal and opposite force of 150 pounds on the man. This principle, which reveals that all changes in motion are the result of applied forces and their reactions, is applicable to all types of motors as well as to jets.

In the propeller-driven aircraft, a certain weight of air

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passes through the propeller blades in a given amount of time. The action of the propeller increases the velocity of this weight of air in a direction opposite to that of the motion of the aircraft. Some force must act on the air in order to accelerate it rearward because all motion is the result of applied forces. The propeller, driven by the reciprocating engine, supplies the motive force necessary to increase the momentum of the air, and the equal and opposite force, or reaction, is the thrust which moves the aircraft through the air. The air passes around the aircraft, however, and is not ejected from within the motor. In jet propulsion, matter is increased in momentum and ejected from within the motor This fact makes jet propulsion different from other forms of propulsion.

The principle of jet propulsion is well illustrated when a man fires a rifle from his shoulder and immediately feels the kick, or recoil. This kick is the equal and opposite reaction to the force which ejected the bullet from the muzzle of the rifle. The bullet is the ejected matter, and the force which accelerates it from zero velocity to about 2,700 feet per second is the unbalanced pressure force created by the explosion of the powder. If the man stood on frictionless skates and fired several shots in rapid succession, the kick, or reaction, would propel him in a direction opposite to that of the bullets, or ejected matter.

One type of jet motor, the rocket, is very similar to the rifle. A combustion chamber corresponds to the cartridge case in the rifle; a nozzle corresponds to the muzzle of the rifle; and the molecules of gases of combustion correspond to the bullets of the rifle, illustrated in figure 2–1. When the rifle is fired, powder is burned and gases are generated at high temperature and pressure. These gases will try to expand in all directions with the same force. But, because the cartridge case prevents expansion in all directions except toward the muzzle, the gases can only escape by pushing the bullet out of the barrel. In the rocket, fuel is burned in the combustion chamber and a large volume of gases is generated at high temperature and pressure. Since there is no bullet to push out of the way, as in the case of the rifle, these gases

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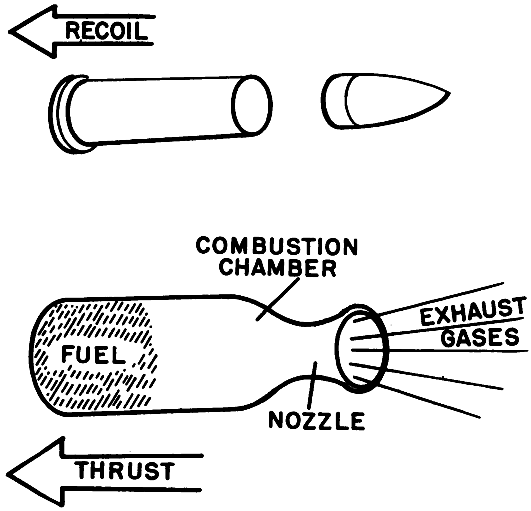

Figure 2–1.—Principle of jet propulsion.

escape through the nozzle at an extremely high velocity—about 5,000 feet per second. The reaction (recoil) of the rifle is very short in duration because only a small amount of powder is burned in a very short time. In the rocket, however, fuel is burned for a much longer time, and the ejection of billions of molecules of gases causes a sustained reaction which is the THRUST of the rocket.

This discussion shows that the reaction which propels a jet engine occurs WITHIN the engine, and does not occur as the result of the exhaust gases pushing against the air.

A gun fired in a vacuum would recoil with almost the same force as it does when air is present. Similarly, a jet-propelled missile—provided it carries the oxidizer necessary for the combustion of the fuel—would operate in a vacuum, under water, or at a very high altitude. In fact, a rocket motor reaches its most efficient operation in a vacuum. The opposite is true of propeller-driven vehicles because the forward push, or thrust, is dependent upon the air for the resisting force.

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Jet motors used in guided missiles depend on heat energy for the force necessary to accelerate the ejected matter, and are called THERMAL JETS ("thermal" meaning "heat"). The heat energy is supplied by a chemical reaction, usually an oxidation (burning) process. In order for this oxidation process to occur, two substances are required—a fuel and an oxidizer, a substance having a large oxygen content.

Thermal jets are classified by the manner in which the oxygen is acquired. The two main classes are: ROCKETS, which carry their own oxidizer as well as fuel; and ATMOSPHERIC JETS, which utilize the oxygen in the atmosphere. The rocket operates independently of its surroundings, while the atmospheric jet is an air-breathing motor, and is limited to operation within the earth's atmosphere.

ROCKETS consist of three major parts—propellant, combustion chamber, and nozzle. The propellant is the combination of fuel and oxidizer necessary for the chemical reaction which generates the gases that are accelerated to high velocity and pass through the exhaust nozzle. Rockets are classified according to the state of the propellant used—solid or liquid.

The solid-propellant rocket, which is essentially a short-duration, single-shot unit, is noted for its simplicity and is used in most short-range missiles. The liquid-propellant rocket is much more complicated than the solid-propellant. Because it can be cooled effectively and since the flow of propellant can be controlled by valves, the liquid-propellant rocket can operate for longer periods of time, and is applicable to long-range missiles.

There are two main types of solid-propellant rockets—RESTRICTED BURNING and UNRESTRICTED BURNING, shown in figure 2–2. In the restricted-burning rocket, the propellant is allowed to burn on only one surface at a time. An example of restricted burning is the manner in which a cigarette burns. In the unrestricted-burning rocket the propellant is allowed to burn on several surfaces at once. As a result, relatively high thrust is produced, but it lasts for only a short period of time as indicated in figure 2–2. The different amounts

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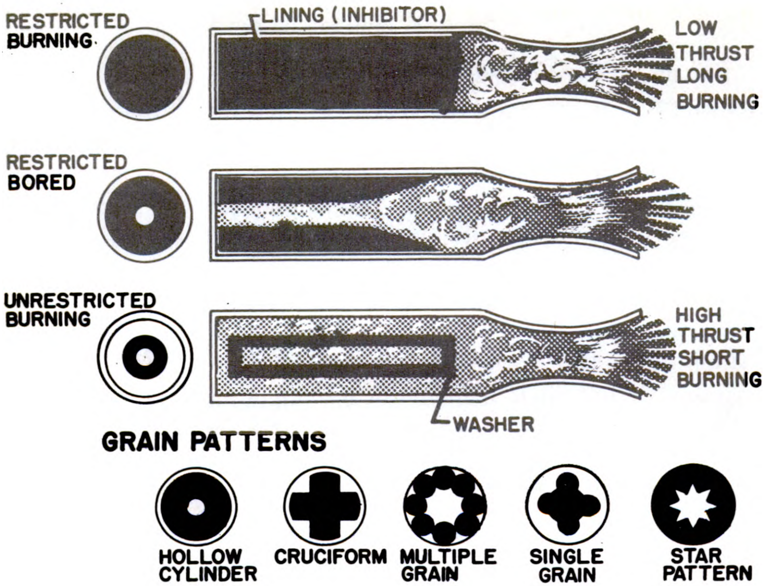

Figure 2–2.—Solid-propellant rockets.

of thrust are obtained by the use of different patterns of propellant grains, some of which are shown in the figure.

In the case of both the restricted- and unrestricted-burning solid propellants, it is essential that no detonation of the propellant takes place because all of the propellant is stored in the combustion chamber. It should be clearly understood that the propellant burns at a definite and controlled rate—it does not explode. To start the combustion process, some form of electrically-detonated squib is ordinarily used to ignite a smokeless or black powder charge, which, in turn, ignites the propellant.

In liquid-propellant rockets, the propellant is fed into the combusition chamber at a controlled rate. The main components of a liquid-propellant rocket are: (1) Propellant tanks for storage of both fuel and oxidizer, (2) a propellant feed system for introducing the fuel and oxidizer into the combustion chamber at the desired rate, (3) a combustion chamber, and (4) a nozzle. Liquid-propellant rockets are

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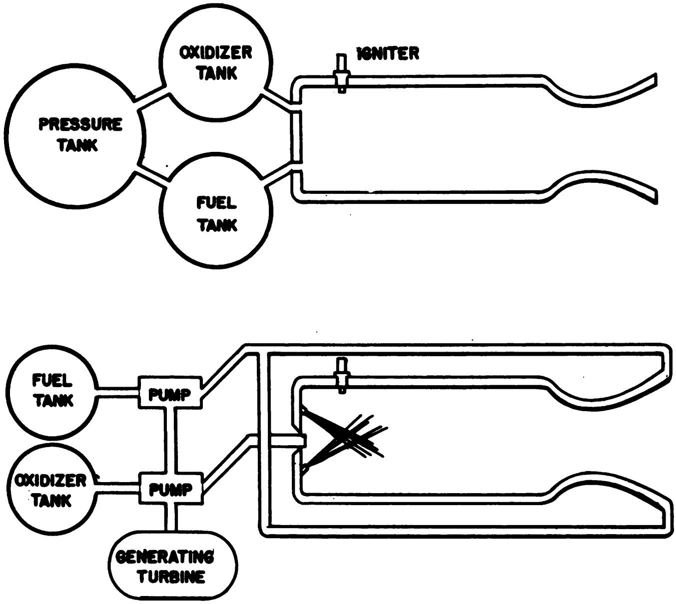

Figure 2–3.—Liquid-propellant rockets.

divided into two classes based on the two types of propellant feed systems—pump and pressure, shown in figure 2–3. Either type may be constructed so that cooling of the combustion chamber is accomplished by circulating the fuel around it, as shown in the figure.

Because rockets carry both fuel and oxidizer, their SPECIFIC FUEL CONSUMPTION—the pounds of propellant consumed per hour per pound of thrust—is much higher than that of other thermal jets. The thrust developed is essentially constant and is independent of the speed of the rocket.

ATMOSPHERIC JETS.—Atmospheric jets take air from the atmosphere, increase its pressure, and feed it into the combustion chamber where it is combined with the fuel. There are two basic methods of increasing the pressure of the incoming air—by using a mechanical compressor, or by utilizing the action of a diffuser (a duct of varying cross section designed to convert high-speed airflow into low-speed

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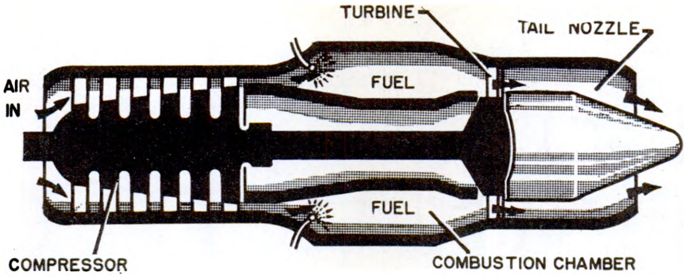

Figure 2–4.—Turbojets.

flow at increased pressure). The three types of atmospheric jets are: TURBOJETS, PULSE jets, and RAM jets.

TURBOJETS are the only type of atmospheric jet which use mechanical compressors. They are particularly suited for use in long-range missiles because of their low specific fuel consumption. In addition, the turbojet is the only atmospheric jet capable of delivering sufficient static thrust (thrust developed with the vehicle not in motion) to enable a missile to take off under its own power. Turbojets are classified according to the type of compressor employed. The two types used are the centrifugal or radial flow, and the axial flow, shown in figure 2–4.

The PULSE JET, which is sometimes referred to as an INTERMITTENT JET, or RESOJET, is another type of atmospheric thermal jet. It is characterized by its pulsing operation which is controlled by a bank of air valves located at the rear of the diffuser. (See fig. 2–5.) These air valves are spring loaded and are normally open so that air can pass through them to the combustion chamber. When the air enters the combustion chamber it is mixed with fuel and ignited. The resulting combustion generates high-pressure gases which try to expand in all directions. The pressure built up in the combustion chamber overcomes the spring tension and closes the air valves, thus causing the gases to expand out of the tailpipe. The escape of the gases causes the pressure in the combustion chamber to be reduced, and the springs to open the air valves. This allows air to enter

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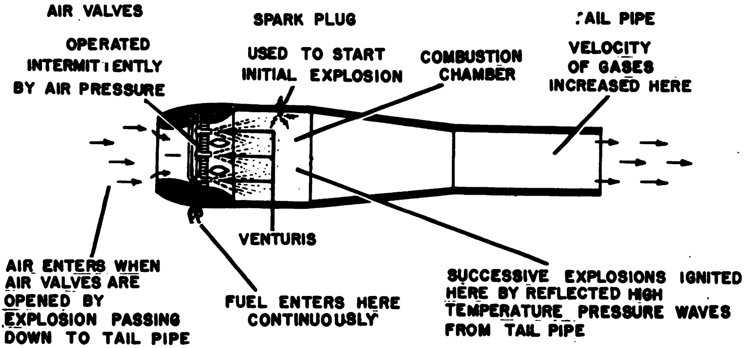

Figure 2–5.—Operating cycle of the pulse jet.

the combustion chamber again, and combustion reoccurs. This cycle is repeated about 50 times per second.

Pulse jets develop approximately 500 pounds of thrust per square foot of area under static conditions, and 780 pounds of thrust at a speed of about 350 miles per hour. This increase in thrust is due to the increased compression of the air by the diffuser. The maximum speed of pulse jets is about 450 miles per hour; and their specific fuel consumption is roughly one-sixth that of a rocket, but is still higher than the turbojet. Pulse jets are economical, light, simple to construct, noisy, and limited to low speeds. They have a very limited application at present for power plants for test missiles.

The RAM JET, which is sometimes called the FLYING STOVEPIPE or ATHODYD, is a compressorless type of thermal jet, as is the pulse jet. It is unlike the pulse jet, however, in that it has no valve bank to restrict the flow of gases to one direction, as shown in figure 2–6. Also, the combustion process in the ram jet is continuous, while that of the pulse jet is intermittent. The ram jet utilizes the action of the diffuser to create a "pressure barrier" which prevents the gases from escaping in the forward direction. In order for this diffuser action to occur, the ram jet must be boosted to a suitable speed, and consequently it cannot produce static thrust.

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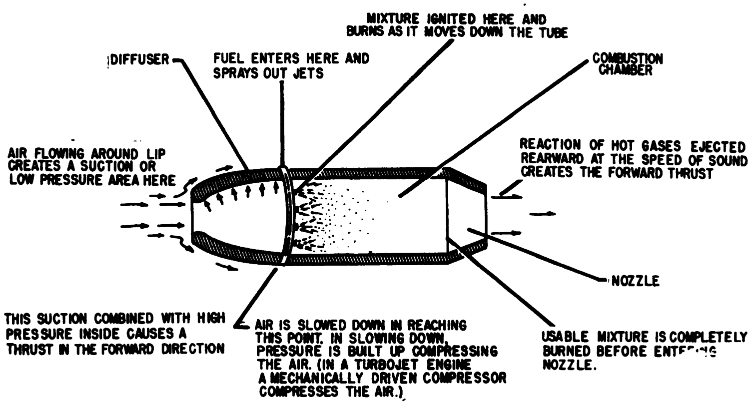

Figure 2–6.—Operating cycle of the ram jet.

Ram jets are classified according to operating speed—subsonic and supersonic. Both classes operate in the manner shown in the figure; the basic difference is in the diffuser design. The ram jet has a higher specific fuel consumption than the turbojet, but at supersonic speeds the ratio of engine weight to developed horsepower is far superior to that of any other atmospheric jet. Ram jets are limited in range only by the amount of fuel they can carry, and can operate up to a theoretical altitude of about 90,000 feet.

Guided missiles must travel at supersonic speeds to reduce effective countermeasures to a minimum, and thermal-jet engines are the only known propulsion devices capable of operating at these speeds. Each of the basic thermal-jet engines discussed in this section has different operating characteristics. For example, the turbojet has a low specific fuel consumption, the pulse jet is simple and economical to construct, the rocket is not limited to operation within the earth's atmosphere, and the ram jet must be boosted to sufficient speed for operation. Each type of jet engine has definite missile applications because of the widely different requirements of the guiding system, launching system, missile size, speed, and tactical use. No one type is the ideal guided missile propulsion system.

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GUIDANCE SYSTEMS

Introduction

The GUIDANCE AND CONTROL component of any guided missile determines the proper flight path to hit the target, and controls the missile so that it follows this determined path. It accomplishes this "path control" by the processes of (1) TRACKING, in which the positions of the target and the missile are continuously determined; (2) COMPUTING, in which the tracking information is used to determine the directions necessary for control; (3) DIRECTING, in which the directions are sent to the control units; and (4) STEERING, which is the process of using the directing signals to move the missile control surfaces by power units. The first three processes of path control are performed by the GUIDANCE SYSTEM, and steering is done by the CONTROL SYSTEM. (Types of control systems are discussed in later chapters of this text.)

In order for these processes to be accomplished, the missile must be in stable flight. That is, the missile must be capable of developing forces which restore it to straight and level flight when it is disturbed by some outside influence, such as a gust of wind. The control of missile stability is called ATTITUDE CONTROL, and is usually accomplished by an AUTOPILOT, which is a part of the control system.

Phases of Guidance

Missile guidance may be divided into three phases—launching, midcourse, and terminal. In the LAUNCHING PHASE, the missile is brought to the proper speed and position so that the midcourse or terminal guidance processes can assume control. The MIDCOURSE PHASE is the major part of the guidance cycle in that here most of the corrections are made for changes in course. The TERMINAL PHASE, which occurs as the missile approaches the target, requires very high accuracy since the missile may have to make sharp turns and undergo high accelerations, especially against moving targets.

In some missiles a single guidance and control system may

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be used for all three phases; in others a different guidance system may be used for each phase in conjunction with a single control system. Also, a separate guidance and control system may be required for each phase. A single missile may utilize one of many combinations of basic guidance systems. These basic types of systems are divided into four groups—(1) self-contained, (2) beam-rider and command, (3) baseline, and (4) homing.

Self-Contained Guidance Systems

The self-contained group consists of the guidance systems in which the intelligence is entirely within the missile. Some of the systems of this type are: PRESET, TERRESTRIAL, INERTIAL, and CELESTIAL-NAVIGATION. These systems are most commonly applicable to surface-to-surface missiles, and countermeasures are ineffective against them.

PRESET SYSTEM.—A missile equipped with a preset guidance system follows a predetermined flight path which is controlled by a mechanism within the missile, and which cannot be corrected after launching. This mechanism, usually a clockwork device, is set according to calculations of range and wind drift made from the known location of the target with respect to the launching point. A typical example of the preset system was that of the German V–2, where range and bearing of the target were predetermined and set into the control mechanism.

The preset system is relatively simple compared to other types; it is dependable, and does not require tracking or visibility. But, because of its poor accuracy due to the fact that conditions along the flight path are not always the same as estimated, and since the flight path cannot be corrected after launching, the preset system has limited application in present guided missiles.

TERRESTRIAL SYSTEM.—The terrestrial or magnetic guidance system is similar to the preset system in that a predetermined course is set into the missile prior to launching; but in addition, a magnetic device in the missile, such as a magnetic compass, monitors the flight path and initiates

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corrections if the missile deviates from it. The German V–1 used this type of guidance in conjunction with a barometer to control altitude, and an air log (similar to the mileage section of an automobile speedometer) connected to a propeller to control range. The accuracy of the magnetic system is greater than that of the preset system, but wind drift can cause large errors because the missile can maintain the same heading and still be blown off course.

INERTIAL SYSTEM.—In the inertial guidance system, a predetermined path is adjusted after launching by devices within the missile which make use of Newton's second law of motion. (This law, which relates acceleration, force, and mass, states that the acceleration of a body is directly proportional to the force applied, and inversely proportional to the mass of the body.) These devices, usually three double-integrating accelerometers, continuously measure the distance traveled by the missile in three directions—range, altitude, and azimuth. Double-integrating accelerometers are devices which are sensitive to acceleration, and by a double-step process measure distance. These measured distances are then compared with the desired distances, which are preset into the missile; and if the missile is off course, correction signals are sent to the control system.

The three accelerometers are usually set up with the sensitive axis of one of them vertical, and the other two in a horizontal plane—one along the flight path, and the other at right angles to it. The output of the one along the flight path is the distance traveled in range. If the output of the one at right angles to the flight path is kept at zero by controlling the missile, then the missile is kept on the desired path in azimuth. In some systems the function of the vertical accelerometer, which keeps the missile at the desired altitude, is performed by a barometric altimeter.

Accelerometers are sensitive to the acceleration of gravity as well as missile accelerations. For this reason, the accelerometers which measure range and azimuth distances must be mounted in a fixed position with respect to the pull of gravity. This can be done in a moving missile by mounting them on a platform which is stabilized by either gyroscopes or star-

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tracking telescopes. This platform, however, must be moved as the missile passes over the earth to keep the sensitive axis of each accelerometer in a fixed position with respect to the pull of gravity. These requirements cause the accuracy of the inertial system to decrease as the time of flight of the missile increases.

Celestial-navigation system.—In this system celestial observations are used to navigate the missile along a predetermined path. These observations are made by a device in the missile, such as an automatically positioned telescope, and the measured readings are compared with preset values to determine whether the missile is on course. The accuracy of this system is independent of range, thus making it desirable for long-range missiles. In the missile system, some device must sight the stars and calculate positions continuously and automatically. This requirement means that the missile must carry complicated equipment, and must fly above the clouds to assure star visibility.

Beam-Rider and Command Guidance Systems

This group consists of the beam-rider systems, the command systems, and modifications of each. These systems may be used for either midcourse or terminal guidance depending on the range. They are used most effectively against aerial targets.

Command systems.—A command guidance system is one in which directional commands are sent to the missile from some source outside it. The missile merely executes these commands. A simple command system is shown in figure 2–7.

In this system the operator visually observes the drone (tracking) and mentally decides the changes necessary in course, speed, and elevation (computing). Commands are then sent to the drone by radio (directing) where a receiver picks them up, and through the control system causes the drone to execute the desired maneuver (steering).

In a command system for surface-to-air missiles, two radars and a computer replace the human operator of the

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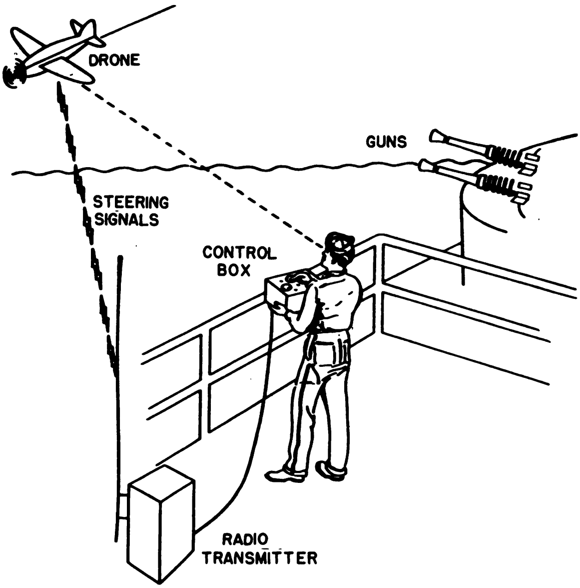

Figure 2–7.—Human command system for target drone.

target-drone system, as shown in figure 2–8. One radar tracks the target and the other tracks the missile. The computer takes the two sets of tracking data and issues commands so that the missile will either collide with the target or pass within the lethal range of the warhead. The command signals may be sent to the missile by radio or by the missile tracking radar. The equipment in the missile is comparatively simple, consisting of a receiver and a control system. The ground equipment, however, is large and complex.

Another type of command system uses a television set in the nose of the missile, which sends back to the ground station or launching aircraft a picture of the target. An operator then sends commands to the missile to make any corrections needed in the flight path. This type of command guidance can be used for surface-to-air, air-to-air, or air-to-surface missiles. The *Roc* missile (fig. 1–9) is an example of an air-to-surface television-controlled missile using command guidance.

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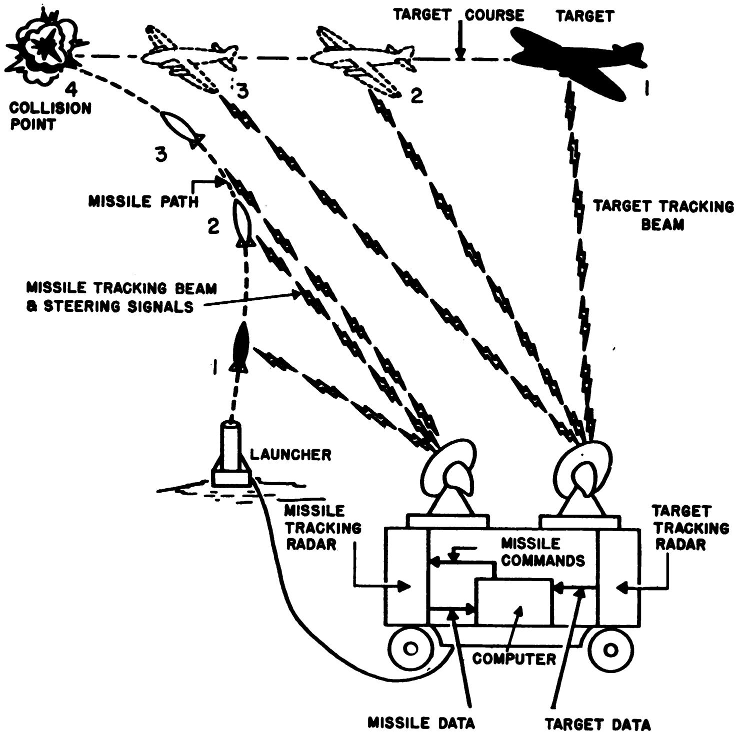

Figure 2–8.—Missile command guidance system.

BEAM-RIDER SYSTEMS.—In the beam-rider guidance system, shown in figure 2–9, a device in the missile keeps it centered in a radar beam. (The basic principles of radar and the general characteristics of a radar beam are discussed in chapter 14 of *Basic Electronics*, NavPers 10087.) The device in the missile locates the center of the beam and sends necessary signals to the control system to remain in it. The radar system (remote from the missile) keeps the beam pointed at the target, and if desired, several missiles may "ride" the beam simultaneously. The accuracy of this system decreases with range because the radar beam spreads out and it is more difficult for the missile to remain in its center.

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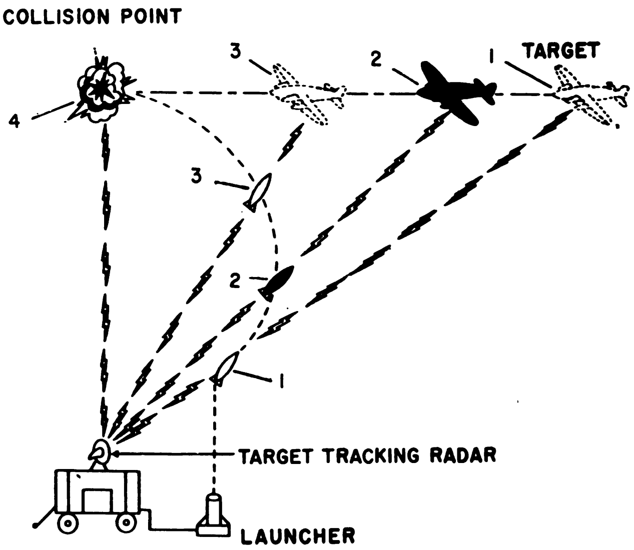

Figure 2–9.—Beam-rider guidance system.

The ground equipment for beam-rider systems is much less complex than that for the command systems, while the missile equipment is more complex. One disadvantage of the beam-rider system is that the missile must follow a continuously changing path which causes it to undergo excessive transverse accelerations.

One variation of the beam-rider system, called the MODIFIED BEAM-RIDER, employs two radars and a computer, and overcomes the problem of high accelerations encountered by the beam-rider missile. In this system, shown in figure 2–10, the target tracking radar feeds target data into the computer, which calculates a collision point at which the missile will intercept the target. The second radar is pointed toward the predicted collision point and the missile follows this beam. If the target does not maneuver, and the calculation of the collision point is correct, the missile will fly a straight-line course, thus eliminating the excessive accelerations of the simple beam-rider system.

Modified beam-rider systems are similar to command guidance systems with the commands being used to position

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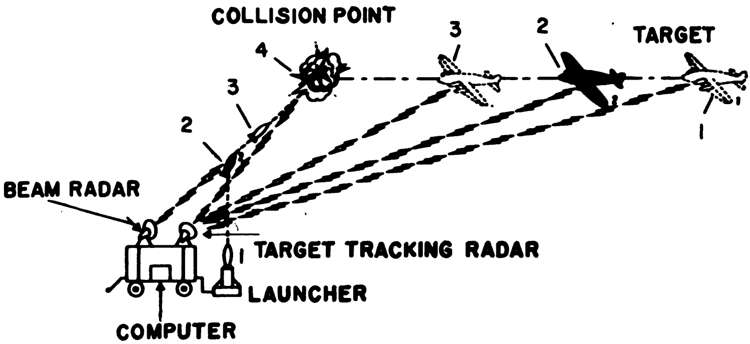

Figure 2–10.—Modified beam-rider guidance system.

the antenna of the guidance-beam radar and thus directing the missile to the predicted point of collision.

Both the beam-rider and modified beam-rider systems are especially applicable to surface-to-air missiles; however, with certain modification they can be used for other applications. For example, a beam-rider can be used for air-launched missiles, whereas the modified beam-rider requires equipment which is too large and complex for airborne applications.

Baseline Guidance Systems

BASELINE GUIDANCE SYSTEMS use the time difference between two radio signals to navigate the missile along a desired path. The signals are transmitted simultaneously from two base stations, shown in figure 2–11, and arrive at the missile at different times. A device in the missile uses the arrival-time difference to control the position of the missile in azimuth. A course of constant-time difference will follow a curved line, called a hyperbola, which bends away from the centerline. In tactical applications the time-difference curve which passes over the target is selected, and the missile equipment is adjusted to navigate along this curve. An example of a baseline system of navigation is LORAN, which is a long-range hyperbolic radio navigation system.

This type of guidance is best suited for the midcourse

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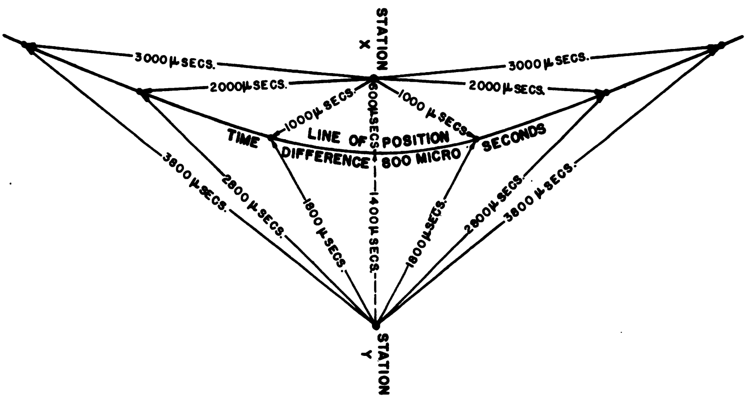

Figure 2–11.—Baseline guidance system.

phase of long-range missiles. Since the system provides azimuth control only, additional equipment is required to control the altitude and range of the missile. The ground equipment is large and complex and is susceptible to radio interference and jamming.

Homing Guidance Systems

HOMING GUIDANCE SYSTEMS control the path of the missile by a device in the missile that reacts to some distinguishing feature of the target. The homing device, usually located in the nose, detects the target by some type of radiation which it gives off; and by some form of LOBING or BEAM-SCANNING technique, it generates directional error signals. Lobing and beam-scanning are methods of determining the direction of echoes, and are commonly used in radar. The radiation which the homing device detects may be in the form of heat, light, radio, or radar. It may be generated by the target or by some outside source and reflected by the target.

Homing systems are divided into three types depending on the source of target radiations. These types are: ACTIVE HOMING, in which both the source which illuminates the target, and the receiver which detects the echoes are carried in the missile; SEMIACTIVE HOMING, in which the

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target is illuminated from some source outside the missile, and the missile receiver utilizes the target reflections; and PASSIVE HOMING, in which the missile receiver detects the natural radiations of the target. The active and semiactive types generally use radar, and the passive type uses heat or light and in some cases homes on a radio or radar transmitter.

Homing is the most accurate of all guidance systems. Its superior accuracy is shown when used against moving targets. There are several ways in which the homing device may control the path of a missile against a moving target. Of these, the more generally used are PURSUIT homing and LEAD homing.

PURSUIT HOMING.—In pursuit homing the guidance system causes the missile to point directly toward the target at all times. The homing device points directly ahead, and keeps the heading of the missile the same as the direction of the target echoes. A missile flying a pursuit course experiences increasingly large accelerations due to turning in the last portion of the course, as shown in figure 2–12. This part of flight path is the most critical; and unless the target is either large or flying a collision course, accuracy is greatly

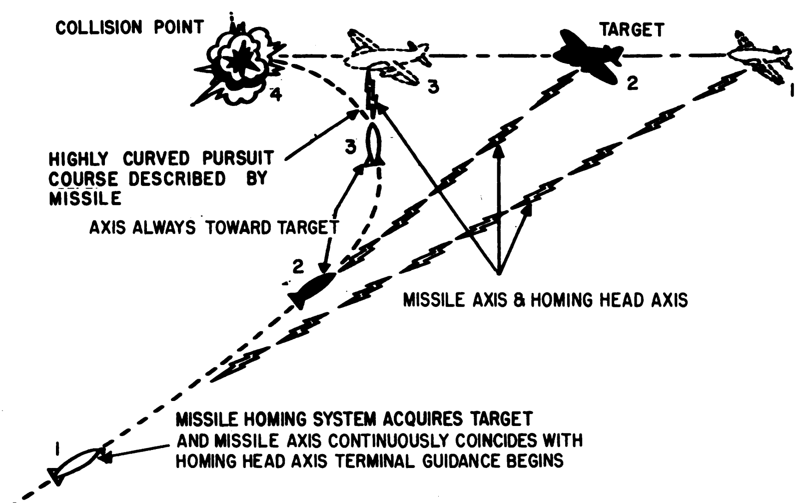

Figure 2–12.—Pursuit homing.

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reduced. As a result, pursuit homing does not have many applications against high-speed targets.

LEAD HOMING.—A lead course is established when the path of the missile maintains a constant angle with the path of the target. In lead homing, the guidance system establishes a lead angle with the target and keeps this angle constant so that the missile travels directly toward a collision point, as shown in figure 2–13. This causes the missile to complete the final and critical part of the flight path as a straight line.

To effect this course it is necessary for the guidance system to measure the rate at which the angle changes. This may be accomplished by having the homing device point toward the target; and any change in the direction of the target from the missile will cause the homing device to turn. The rate at which it turns can be measured by a rate gyroscope. These additional functions require that the homing system for a lead course be more complex than a system for a pursuit course.

One of the main limitations of homing systems is that of

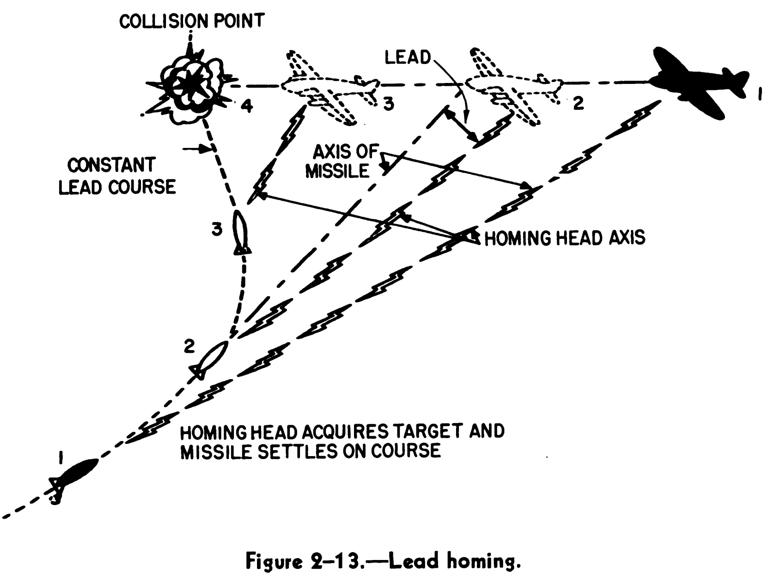

Figure 2–13.—Lead homing.

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range. Also, homing devices must have high directional sensitivity so they will not be confused by multiple targets. Because of these problems it is necessary to place the missile in the vicinity of the target and pointing toward it. This may require the initial part of the course to be controlled by another type of guidance system, such as the beam-rider.

Control Methods

Attitude control of a missile is necessary before guidance can be applied. There are three general methods of providing attitude control—by WEATHERCOCK STABILITY, PROPORTIONAL CONTROL, and BANG-BANG CONTROL.

Weathercock stability is the simplest method because it can be built into the missile airframe. The surfaces are constructed so that the forces developed by the airstream point the missile in the direction of flight and tend to keep a certain side up, as in airplanes. Weathercock stability is a great help, but it is not sufficiently accurate for high-speed long-range missiles.

To obtain the accuracy required by these missiles it is necessary to equip them with a control system which causes the desired changes or corrections in the path or attitude of the missile. There are several types of control systems presently in use; and in general, they perform this function by either the proportional or bang-bang method.

In proportional control, the correcting action caused by the control system is proportional to the amount of error. This error may be either steering signals from the guidance system or attitude-control signals from the stabilizing system (autopilot). This method of control, although difficult to perform, is suitable for high-speed applications because of its fast response, high accuracy, and smooth operation.

In bang-bang control the correcting action is either full on or full off. When an error signal is sent to the control system it moves the steering devices the maximum amount, then returns them to neutral very quickly. This action is called a "peck." Small errors require only a few pecks for correction, while large errors require more. In some systems the time of a peck is made longer for large error signals.

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This method of control is less complex and less accurate than the proportional method, but it is much better than weathercock stability. Because of the pecking action, it causes vibrations in the missile, and is not used in supersonic applications.

WARHEADS AND FUZES

Like any other vehicle, the guided missile must carry some form of useful burden if it is to accomplish the intended objective. In missile terms, the useful burden is called the PAYLOAD. Physically, the payload merely occupies one or more of the sections of the airframe, and it contributes nothing to the functions of the vehicle, such as guidance, propulsion, or control. But in the total system, it is the component of greatest value, since all the actions of the missile serve as the means for insuring the effective delivery of the payload.

In research and test missiles, the payload often consists of telemetering units, which collect data during flight, convert the information into radio signals, and transmit them to receivers at a recording site. In some test missiles, dummy payloads are carried which have the same physical characteristics as the corresponding devices which the missile will carry as an operational weapon. But in its military role, the guided missile is launched with a payload composed of one or more WARHEADS and one or more FUZES. The warhead is a device capable of destroying or damaging an enemy target. The fuze is a triggering mechanism used to initiate the actions of the warhead and which determines the exact moment of release of the destructive forces.

Types of Warheads

Many of the warheads developed for other kinds of weapons can be modified or adapted for use in guided missiles. Some of these may present special problems to the missile designer, but almost any sort of destructive device employed in conventional weapons may also be carried by guided missiles. Among the types of warheads which might be used are: External blast, fragmentation, shaped charge, explosive pellet, chemical, biological, and atomic.

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EXTERNAL BLAST WARHEADS.—This type of warhead causes damage by means of a high-pressure wave, or blast, which results from the detonation of an explosive substance. When set off by a suitable impulse, the explosive material undergoes a sudden chemical change in which energy is released almost instantaneously. Gaseous products are formed and large quantities of heat are generated. The destructive effect results from the high pressure produced by the rapid heating of the gases.

Blast warheads are very effective against ground targets and have been used in many surface-to-surface and air-to-surface missiles. They are less effective against aircraft, since in the atmosphere the pressure wave dissipates rapidly with distance, and the explosion must take place very near the aircraft in order to damage it. Large blast warheads can cause great damage to ground installations, which must be of special construction to withstand them; and damage occurs hundreds of feet from the point of detonation. The V–1 buzz bomb, which carried a warhead consisting of about 2,000 pounds of high explosive, caused destruction and damage over an area equal to an average city block.

FRAGMENTATION WARHEADS.—These warheads operate by bursting a metal case containing a high-explosive charge. Upon explosion, the container is shattered into hundreds of fragments which fly out at high velocities; and these are capable of damaging targets at considerable distances from the point of detonation. For this reason, this sort of warhead is very effective against aerial targets and is often employed in air-to-air and surface-to-air missiles. Usually the warhead does not penetrate the target but is detonated by the fuze at some distance from it which allows the full destructive effect to be realized.

The factors which influence the destructive action of the warhead are the size of the fragments, their velocity, and the angle at which they are ejected. Fragment size is controlled by the designer by weakening the case at certain points. The fragment velocity is controlled by the shape of the container, the ratio of explosive weight to metal weight, and by the type of explosive used. The angle at which most of the

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fragments are emitted depends on the shape of the container and the point within it at which the detonation takes place.

SHAPED-CHARGE WARHEADS.—Shaped charges, also called CAVITY CHARGES, make use of the MUNROE EFFECT, in which the explosive power is concentrated by shaping the explosive material. Experiments show that if a regular cavity such as a conical hole is molded into the side of an explosive charge nearest the target, the effect on the target is increased over the effect obtained with the same charge without the cavity. The presence of the hole brings about a concentration of the explosive force similar to the way in which light can be focused into an intense beam by a glass lens.

In the explosion of a shaped charge, a beam of very hot gas, called the JET, is ejected in which the gas particles have an extremely high velocity. If the cavity is lined with some material that can be broken into small pieces or can be melted by the explosion, the efficiency of the charge is greatly increased. The small particles of the liner are carried by the jet, which is increased in weight, and as a result, it can penetrate a thick target, acting somewhat in the manner of a needle. Among the applications of the Munroe effect are the Army's BAZOOKA projectile and also certain types of demolition charges used to blow holes through reinforced concrete structures.

When employed in guided missile warheads, shaped-charge explosives have possibilities of great effectiveness against both aircraft and heavily armored surface targets.

EXPLOSIVE-PELLET WARHEADS.—A warhead of this type contains a number of small explosive charges, or pellets, each of which is separately fuzed. When the main warhead is detonated, the pellets are ejected but withstand the force of the explosion and are hurled intact toward the target. The pellets then detonate either on impact or after penetrating the target skin. The total destructive effect combines both blast and fragmentation effects, since blast damage is great when the individual charge is exploded, regardless of whether the explosion occurs at the skin of the target or after penetrating it.

The explosive-pellet is an ideal weapon for use against

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enemy aircraft. Its full development is dependent upon perfecting a fuze for the individual charges that can withstand the initial blast of the principal warhead while still insuring explosion on or within the target.

Chemical warheads.—This type may contain either war gases or incendiary materials. Warheads containing gases may liberate any of the well-known types such as mustard gas, lewisite, or some newly developed chemical. The effects produced are either denial of the use of the target area or personnel casualties within the area. Missiles equipped with chemical warheads also serve as possible counterthreats to initiation of gas warfare by the enemy.

The incendiary warhead contains a material that burns violently and is difficult to extinguish while covering a large area after release from the warhead. Incendiary weapons are useful principally against ground targets.

Biological warheads.—A biological weapon delivered by a missile would contain living organisms capable of disrupting personnel activities in the target area by causing sickeness or death to the inhabitants.

Atomic and thermonuclear warheads.—In this type, destruction and damage result from the processes of atomic fission or fusion. The destructive effects are blast, heat, and liberation of radiation. The detonation results in death, sickness, and the denial of the use of large areas as a result of the release of radioactive elements.

Types of Fuzes

The missile warhead is activated by the actions of one or more fuzes, which release the destructive forces after certain conditions have been fulfilled. The type of fuzing employed determines whether the warhead is detonated at a distance from the target, upon impact with it, immediately following penetration, or at some fixed time after penetration of the target skin. The missile warhead is generally detonated in one of the three relations with the target shown in figure 2–14.

The most effective type of fuze for a given missile depends

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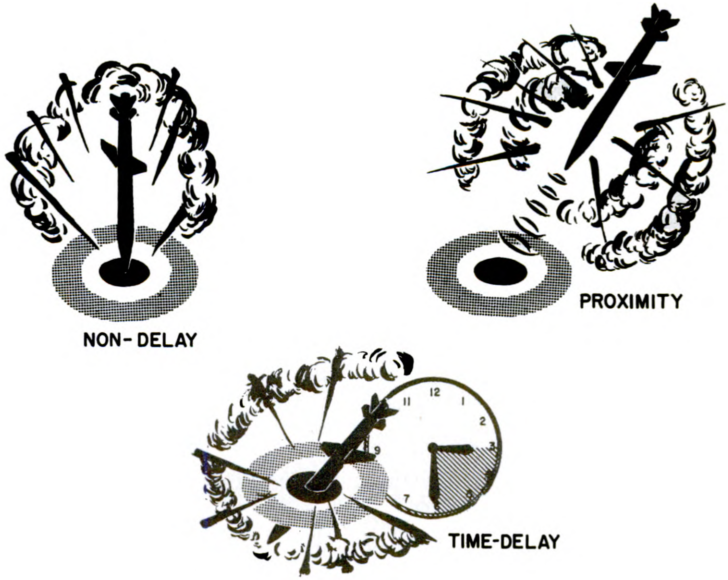

Figure 2-14.—Types of fuzing.

upon the nature of the target and the possibilities of the warhead for causing damage. The types often employed in missiles are the IMPACT, GROUND-CONTROLLED, and PROXIMITY fuzes.

IMPACT FUZES.—Impact fuzes are actuated by the inertial force exerted when the missile strikes the target. If detonation takes place at the moment of impact, the fuze is of the NON-DELAY, or INSTANTANEOUS type. If the detonation takes place some time after penetration, the fuze is said to be of the DELAY type.

GROUND-CONTROLLED FUZES.—In ground-controlled fuzing, some device is used for measuring the distance from the missile to the target. The control device is not mounted in the fuze but on the ground; and when the proper space relationship exists between the missile and its target, a signal is sent to detonate the fuze from the control point on the ground.

PROXIMITY FUZES.—Fuzes of this type are actuated by the influence of some property of the target and are detonated

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at a distance which allows maximum damage to take place. Five general classes of proximity (also called VT, or variable-time) fuzes can be distinguished according to the property to which the device responds. These are radio, pressure, acoustic, photoelectric, and electrostatic fuzes.

Radio fuzes contain miniature transmitters and receivers. In flight, radio signals are radiated, some of which are reflected by the target. At the proper time, the action of the reflected waves causes an electronic switch to close and fire the detonator. Fuzes of this kind have been developed to a high degree of accuracy and dependability. They operate effectively both in darkness and daylight and in all kinds of weather.

Proximity fuzes which respond to changes in pressure generally lack the sensitivity and reliability required for guided missile applications, but in some cases they are useful against surface targets. The problems of the acoustic proximity fuze, which responds to sound, were studied by the Germans at Peenemunde to determine the characteristics of these devices in supersonic missiles. Their wind-tunnel experiments proved that sound waves can be received readily by missiles traveling at speeds in excess of sound velocity. The acoustic fuze has the valuable property of all-weather, day-or-night effectiveness; but it also has the disadvantage that it is subject to local vibration and noises generated within the vehicle as well as to the sound waves by which it senses the target. The Germans also investigated the possibilities of the electrostatic system of fuzing in which the detonating influence is the electric field of the target. Attempts to develop the fuze were unsuccessful—probably because of the variable nature of the electrostatic field surrounding possible targets. Photoelectric fuzes react to external light sources; and ordinarily they are inoperable at night or in conditions of low visibility.

Of these various types of proximity fuzes, the radio system appears to be the most reliable and effective for missile applications.

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LAUNCHERS

Guided missiles are fired from mechanical structures called LAUNCHERS, which provide the means for getting the missile into the air and flying in the correct direction. Some launchers provide initial guidance by constraining the vehicle to move in the desired path for a short time after firing. Others simply support the missile in the proper attitude before firing and exercise little or no control afterward.

The type of launching equipment suitable for a specific missile is determined largely by the amount of acceleration which the weapon's airframe and inner components can tolerate; its flight characteristics; and the thrust developed by its propulsion system at launching. Upon leaving the launcher, the missile must be in stable flight and under the control of a guidance system. The amount of acceleration permissible determines the time the vehicle must be controlled by the launcher, and this in turn determines the complexity and length of the launcher itself. Missiles which develop large amounts of thrust and which can tolerate high acceleration require much shorter launchers than are necessary for low-acceleration, low-thrust missiles of comparable operating speed. Rocket-propelled missiles can be launched from simple platforms. The atmospheric jets require fairly long launchers and also the assistance of an outside thrust-producing device. The auxiliary thrust may be provided by the launcher itself, acting as a catapult, or else BOOSTERS may be used.

Guided missile boosters are thrust-producing devices which can be attached to the missile to give it initial acceleration. The booster is usually an unrestricted-burning, solid-propellant rocket motor. The booster is similar in principle to JATO (jet-assisted takeoff) units used with aircraft. In most cases, it drops from the missile after the thrust it delivers has ceased. Most ground-launched missiles are fired with the aid of boosters in order to make the missile smaller and lighter and to bring the vehicle to operating speed in a short launching distance.

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Launchers for guided missiles used as military weapons must meet the requirements of combat in addition to providing the means for getting the vehicle into flight. The ideal tactical launcher is maneuverable, it permits the weapon to be trained in any desired direction, and it is capable of high rates of fire. The structure is as compact and as simple as possible in construction; it combines minimum weight with sufficient strength to support the missile; and it must be able to withstand shock, vibration, and the rearward blast of the propellant. The equipment must be easy to assemble and disassemble while allowing access to the missile for final adjustments prior to firing. A further requirement for tactical ground launchers is that the structure be easily covered or camouflaged to conceal the location of the firing site from enemy reconnaissance.

TYPES OF LAUNCHERS.—The following general types of launchers are used in all phases of guided missile work at the present time:

1. TRAINABLE PLATFORM LAUNCHERS. These are employed for vertical launchings of large missiles from the ground. The launcher consists principally of a platform on which the missile is mounted in an upright position and contains a training ring used to position the weapon in azimuth.

2. TOWER LAUNCHERS. These are structures of the derrick type. Towers are used for vertical or near-vertical firing of high-altitude missiles. The vehicle is aimed by the tower in the desired angle before firing and is forced to move in that direction so long as it travels within the launcher.

3. RAIL LAUNCHERS. This group includes both vertical-rail launchers and ramp launchers. The vertical-rail type serves the same purpose as the vertical tower, while employing one or more rails to determine the initial path of the missile. The ramp launcher trains the missile for flight at an angle of elevation other than vertical, constraining it at the start by means of rails. Fixed vertical-rail launchers are often used with missiles employing command or beam-rider guidance, since these weapons can be guided toward

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the target during flight and need not be fired directly toward it by the launcher.

4. GUN LAUNCHERS. This type is a gun which fires the missile as though it were a projectile. The gun launcher is well adapted to surface firing of missiles against aerial targets. It has the advantages of comparative simplicity and a high rate of fire; and since it provides sufficient acceleration to bring the missile to operating speed, it eliminates the need for boosters.

5. CATAPULTS. These are machines which either release high-pressure energy or utilize electrical power to accelerate a sled or car to which the missile is attached. The catapult both aims the missile and develops high initial thrust so that the weapon can be launched without a booster.

6. ZERO-LENGTH LAUNCHERS. A zero-length launcher is a structure that is shorter than the missile fired from it, and which exercises negligible aiming action after ignition.

LAUNCHING FROM AIRCRAFT.—Air-launched missiles are fired from zero-length launchers which are often suspended from the underside of the wings in the manner illustrated in figure 2–15. Some airborne launchers are short racks similar to those used for firing rockets. Others are streamlined pylons to which the missiles are attached by two or more lugs. A typical pylon installation contains four launchers, each of which supports one missile. The electrical cables of the weapon-control circuits are carried within the pylons and are attached to the missiles by means of detachable UMBILICAL

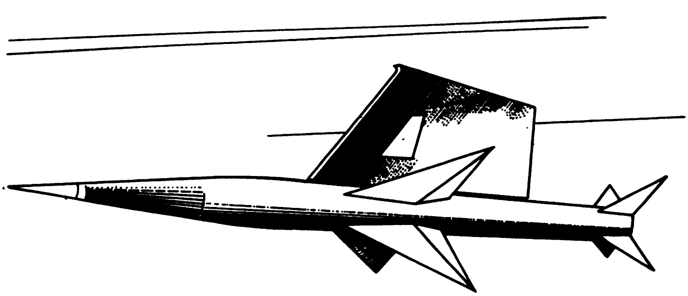

Figure 2–15.—Airborne missile mounted for launching.

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connectors. The missile launching controls include the FIRING circuits, which initiate the launching, and the SAFETY circuits, which prevent premature firing of the weapon.

The aircraft heading provides the directional control, or means of training the missile; and the speed of the plane contributes to the initial velocity of the vehicle upon firing. In addition to being very mobile, the aircraft adds its own range to that of the missile so that targets otherwise inaccessible can be reached by the air-launched weapon.

In the preceding pages of this chapter the fundamental components of military guided missiles have been discussed and the functions and characteristics of the various types have been pointed out. It is necessary that the GF understand not only the actions of these components, but he must also know the principal factors which influence the missile while it is in flight. Accordingly, the following chapter is concerned with the medium through which the missile flies, some of the characteristics of supersonic speeds, and the methods and devices used for steering.

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QUIZ

1. A missile employing the preset guidance system is limited in range
   a. to 1,500 miles
   b. principally by fuel capacity
   c. by the earth's contours
   d. by atmospheric conditions
2. The inertial reference system uses in its operation
   a. pitch, yaw, and roll gyros
   b. two tracking telescopes
   c. three accelerometers
   d. a magnetometer
3. The purpose of the guidance control system is to
   a. steer the missile
   b. stabilize the missile in flight
   c. delay arming of the warhead
   d. detect and correct any error in the missile flight path
4. Upper atmosphere research vehicles would normally use a
   a. reciprocating engine
   b. unrestricted solid-rocket motor
   c. ram jet
   d. liquid-rocket motor
5. What are the four things necessary for successful missile guidance?
   a. Tracking, computing, aerodynamic stability, and supersonic speed
   b. Supersonic speed, booster, tracking, and directing
   c. Tracking, computing, directing, and steering
   d. Computing, radar beam, booster, and steering
6. Of what does the guided missile airframe consist?
   a. Missile framework and aerodynamic surfaces
   b. Framework and jet motor
   c. Aerodynamic surfaces and guidance control system
   d. All of the missile including the internal parts
7. The two types of liquid rockets are
   a. restricted and unrestricted burning
   b. restricted and pump feed
   c. pressure feed and pump feed
   d. unrestricted and pump feed
8. The guidance system most likely to be used in a SAM would be
   a. inertial
   b. magnetic
   c. celestial
   d. beam-rider

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9. The type of propulsion most likely to be found in a guided missile would be
   a. mechanical
   b. thermal
   c. terra
   d. hydro

10. In order for it to function properly, a __________ must be boosted to operating speed.
    a. rocket
    b. turbojet
    c. ram jet
    d. pulse jet

11. The pulse jet contains __________ moving part(s).
    a. 2
    b. no
    c. 3
    d. 1

12. The component of a rocket which converts heat energy to velocity energy is known as the
    a. combustor
    b. nozzle
    c. diffuser
    d. igniter

13. The component of a ram jet which changes a high-speed low-pressure flow of gas into a low-speed, high-pressure flow is known as the
    a. diffuser
    b. combustor
    c. igniter
    d. nozzle

14. In reaction motors not normally carrying their own oxygen supply, a __________ offers the greatest speed.
    a. pulse jet
    b. ram jet
    c. turbojet
    d. rocket

15. Ram-jet engines are classed primarily according to their
    a. weight
    b. speed
    c. length
    d. fuel

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16. Which of the following is a correct statement?
    a. Supersonic ram jets are most efficient at Mach 0.8.
    b. Pulse jets can develop no static thrust.
    c. Rocket motors are incapable of flight within the earth's atmosphere.
    d. Pulse jets cannot attain supersonic speed.

17. While burning, the propellant in a rocket motor
    a. gets its oxygen from the atmosphere
    b. supplies its own oxygen
    c. will fail at 20,000 feet due to lack of oxygen
    d. carries a compressor to augment its oxygen supply

18. Boosters are added to guided missiles
    a. for use in case the main propulsion unit fails
    b. to help get the fuel in the combustion chamber
    c. to attain effective operating speed
    d. to eliminate the need for launching ramp or platform

19. An AAM would use which of the following guidance systems?
    a. Beam-rider
    b. Preset
    c. Celestial
    d. Baseline navigation

20. The guidance system that has the highest degree of accuracy at long ranges is the __________ system.
    a. radar
    b. radio navigation
    c. beam-rider reference
    d. preset

21. Select the type of guidance system which is the most difficult to countermeasure.
    a. Radar
    b. Radio navigation
    c. Beam-rider
    d. Preset

22. The three phases of guidance are
    a. midcourse, terminal, and initial
    b. initial, baseline, and terminal
    c. steering, midcourse, and homing
    d. initial, midcourse, and homing

23. Terrestrial reference and radio navigation would normally be used during the __________ phase of guidance.
    a. homing
    b. command
    c. final
    d. midcourse

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24. A programmer would most likely be a component part of the __________ guidance system.
    a. command or beam-rider
    b. preset or homing
    c. celestial or inertial
    d. terrestrial or command

25. Which of the following methods is most likely to be used to increase accuracy of a missile using a terrestrial guidance system?
    a. Use a biological warhead to get a larger blast effect.
    b. Incorporate a homing system for terminal guidance.
    c. Incorporate a beam-rider for initial guidance.
    d. Use radar navigation for terminal guidance.

26. Select a disadvantage of the terrestrial guidance system as compared to the preset.
    a. It is decidedly inaccurate.
    b. Greater visibility is required.
    c. It is subject to countermeasures.
    d. It is more complicated.

27. Which of the following terrestrial characteristics did the V–1 utilize?
    a. Air pressure and gravity
    b. Magnetic field and gravity
    c. Temperature and gravity
    d. Air pressure and magnetic field

28. What advantage does self-contained guidance have over command guidance?
    a. It is less susceptible to countermeasures.
    b. It is more adaptable to moving targets.
    c. It can be more readily used in SAM's.
    d. It needs a single radar beam only.

29. The __________ best represents a type of command guidance.
    a. German V–1
    b. Dove
    c. German V–2
    d. Drone

30. In active homing the target illuminating transmitter is located in the
    a. parent aircraft
    b. missile
    c. ground-control station
    d. target

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31. The methods commonly used to detonate fuzes are
    a. setback, creep, inertia
    b. impact, proximity, external command
    c. heat, setback, external command
    d. impact, heat, and setback

32. The types of explosive warheads are
    a. blast effect, fragmentation, shaped charge, explosive pellet, and atomic
    b. blast effect, fragmentation, atomic, and chemical
    c. blast effect, chemical, incendiary, and atomic
    d. blast effect, fragmentation, shaped charge, and chemical

33. A warhead is placed in a guided missile for the sole purpose of
    a. providing power for sustained flight
    b. causing destruction of the missile at the end of the flight
    c. causing destruction or damage to the enemy target
    d. causing missile detonation on impact with the target

34. Infrared is utilized in what type of homing?
    a. Active
    b. Semiactive
    c. Passive
    d. Semipassive

35. The most dependable type of proximity fuze when used against airborne targets is the __________ fuze.
    a. radio
    b. acoustic
    c. photoelectric
    d. electrical

36. The most effective type of warhead to be used against airborne targets is the
    a. shaped charge
    b. fragmentation
    c. armor piercing and incendiary
    d. incendiary and shaped charge

37. Radio navigation guidance is primarily based on the theory that
    a. baseline transmitters emit different amounts of radiated power
    b. low-frequency energy can travel faster than high-frequency energy
    c. radio energy travels at a constant rate of speed
    d. the speed of travel depends on the distance

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38. A disadvantage of the radio navigation guidance system is that it
    a. is limited to one missile at a time
    b. requires a ground radar system
    c. requires bulky and complicated gear in the missile
    d. is very susceptible to countermeasures

39. An advantage of the beam-rider system is
    a. the transverse accelerations are greater
    b. the missile follows a line-of-sight course
    c. there is greater accuracy at increased range
    d. several missiles can be controlled in one beam

40. A missile using radio navigation guidance (loran), receiving two nonsimultaneous signals will fly
    a. a straight line between the stations
    b. a curved line between the stations
    c. at right angles to both stations
    d. a curved line toward one of the stations

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CHAPTER 3

FACTORS AFFECTING MISSILE FLIGHT

The study of the basic problems of missile flight, control, and stabilization properly begins with a description of the atmosphere, the medium in which the weapon travels. The atmosphere, the immense sphere of nitrogen, oxygen, and other gases in which we live, has well-defined physical properties, many of which are of primary importance in studies of the motions of guided missiles, as well as other types of aircraft. It is the purpose of this chapter to introduce some of these basic properties of the atmosphere, some of the elementary principles of aerodynamics, and to point out the more frequently used types of control surfaces and the methods in which they are employed in military missiles.

THE ATMOSPHERE

Most of the present-day guided missiles and those planned for future use will have at least a part of their flight path within the earth's atmosphere—a gaseous shell surrounding the earth with a height of roughly 250 miles. As a result, their efficient operation will be largely dependent upon the various effects associated with motion through the air. Also, in order to get very long ranges with self-propelled missiles, they must go very high and into regions that possess different characteristics than those of sea level.

One of the most important characteristics of the atmosphere is the change with altitude in the DENSITY of the air. Density is the mass of air in a given volume. Because air is made up of gas particles, air density is also a measure of the number of particles in a given volume. For example, the number of gas particles in a cubic inch of air at sea level is

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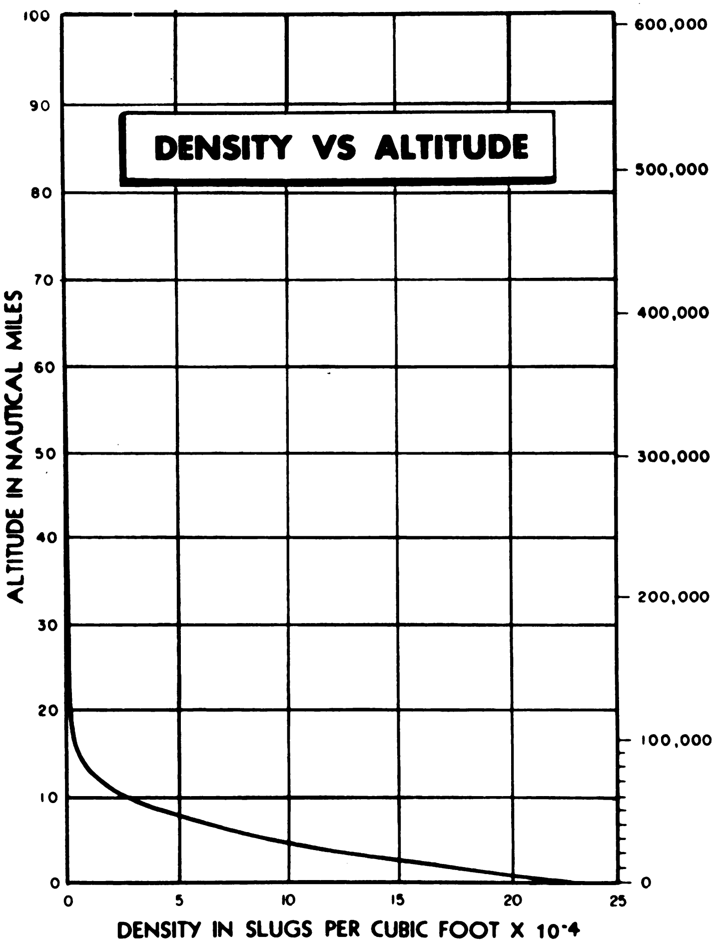

Figure 3–1.—Density vs. altitude.

about 420 billion billion. At 35,000 feet the number of particles in a cubic inch is about 110 billion billion. Although this is still a very large number, it is only about one-fourth of 420 billion billion. As shown in figure 3–1, density changes very rapidly in the lower region of the atmosphere. This is because most of the air is concentrated near the surface of the earth—half of all the air particles that make up the atmosphere are packed in a layer between sea level and 18,000

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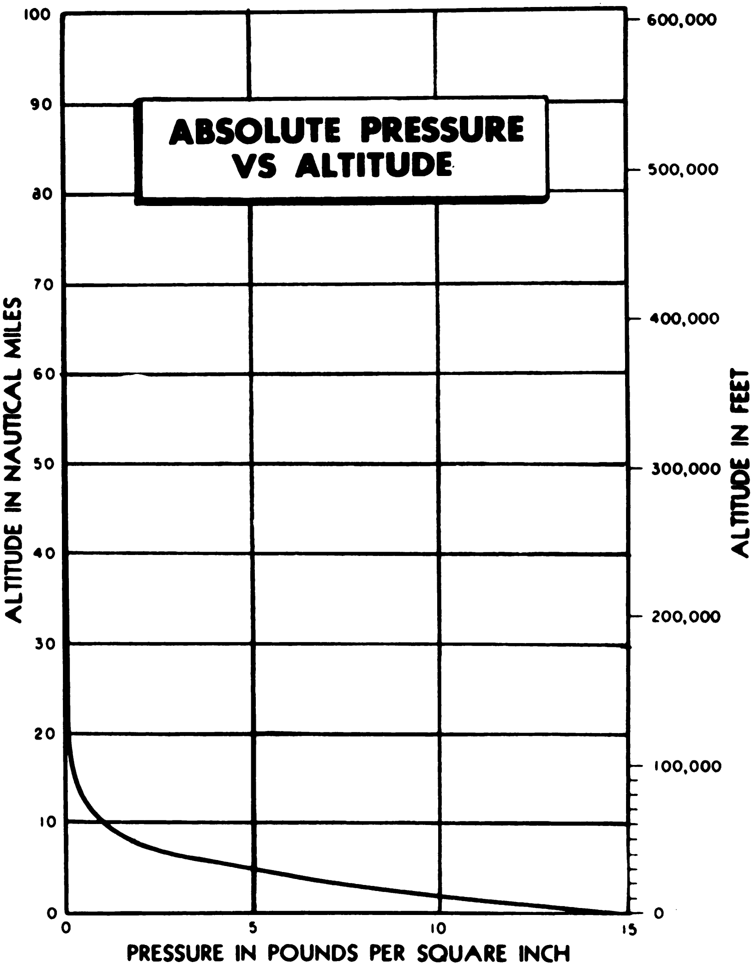

Figure 3–2.—Pressure vs. altitude.

feet. Because of this, a missile flying at 35,000 feet encounters less air resistance—that is, has less drag—than a missile flying near sea level, simply because it hits fewer gas particles per second.

Another characteristic of the atmosphere, which is closely associated with density, is the change with altitude in ABSOLUTE PRESSURE, shown in figure 3–2. The absolute pressure

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existing at any point in the atmosphere is the force per unit area exerted by the air against a fixed object. (If the object were moving with respect to the air, there would be a dynamic pressure acting on it, which would be in addition to the absolute pressure of the atmosphere.) In contrast to density, which is measured in mass per unit volume, pressure is measured in force per unit area (for example, pounds per

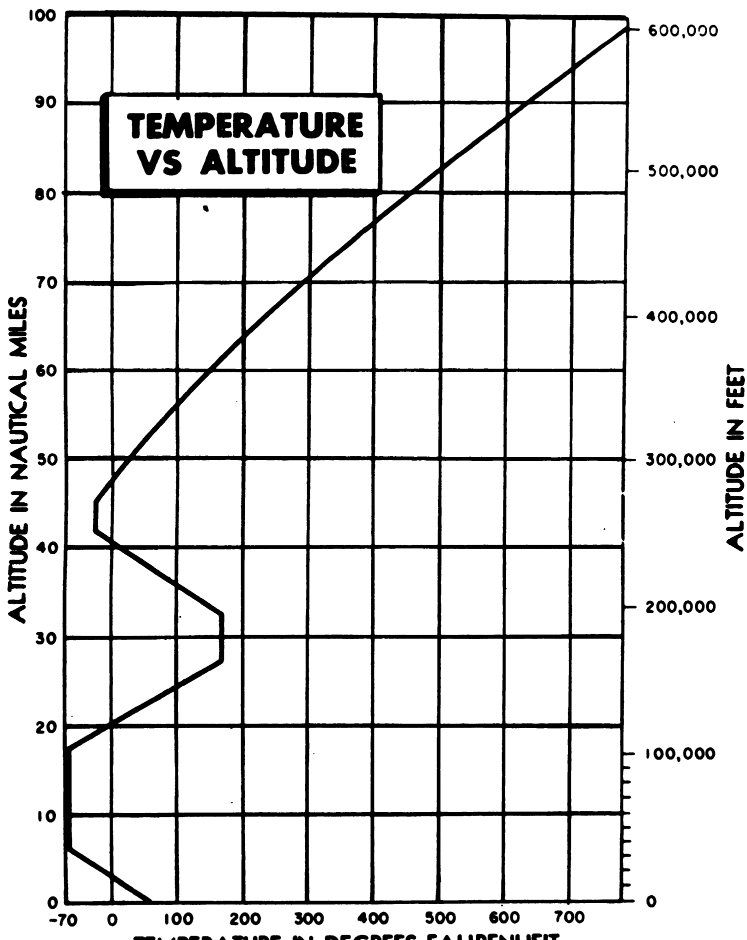

Figure 3-3.—Temperature vs. altitude.

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square inch). The absolute air pressure acting on each square inch in the earth's atmosphere at any given altitude is actually the weight of a square inch column of air extending from the altitude in question to the outer limit of the atmosphere. As a point of comparison, the increase in pressure only 34 feet below the surface of a lake is equivalent to the pressure developed on the earth's surface by the entire weight of the atmosphere.

Another characteristic of the atmosphere which also varies with altitude is the TEMPERATURE. However, it does not follow the same pattern as the density and pressure, except at low altitudes, as shown in figure 3–3. From sea level to about 35,000 feet, the temperature usually drops steadily at the rate of approximately 3½° F. per 1,000 feet. It then remains fairly constant at −67° F. up to about 105,000 feet where it starts to increase at a steady rate until another constant-temperature zone is reached. This zone lasts for almost ten miles, at which point the temperature starts decreasing again. The procedure then repeats itself—that is, a second temperature minimum is reached, and then after a short, cold (about −27° F.), constant-temperature zone, it starts rising again. These temperature minimums mark the boundaries between the three regions of the atmosphere: the troposphere, the stratosphere, and the ionosphere, shown in figure 3–4.

The TROPOSPHERE is the lowest layer of the atmosphere, and extends from the surface of the earth to a height of about six miles. It is made up of 99 percent nitrogen and oxygen by volume, and accounts for three-fourths of the weight of the atmosphere. Within this layer, temperature normally decreases with altitude, and it is the region in which there is a relatively large amount of moving air currents which we call wind; different types of clouds, either high above or resting on the ground (fog); snow, rain, hail, thunderstorms; and the four seasonal changes. In certain areas of the upper part of the troposphere, prevailing westerly winds from about 100 to 300 miles per hour form the commonly called "jet stream."

Because of the high density of the troposphere, airfoils can be used efficiently for control of missiles in this region;

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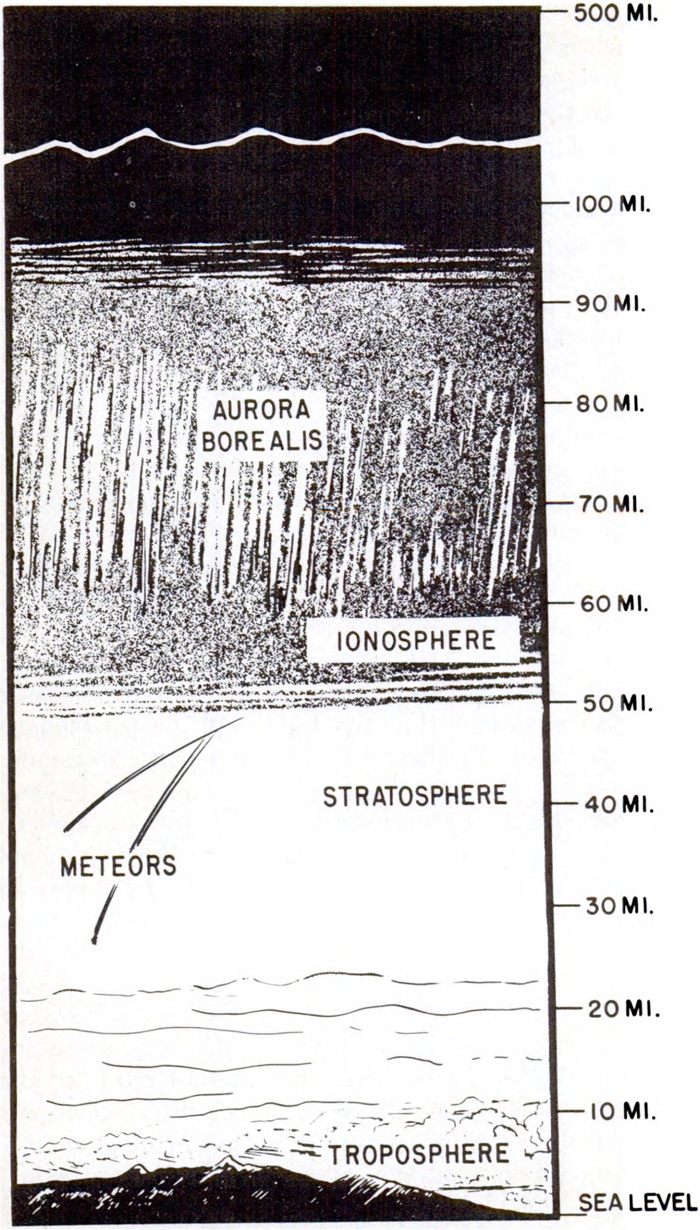

Figure 3-4.—Atmospheric regions.

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and propellers are practical for low-speed power plants. However, this high density also causes a large amount of drag—the dense lower atmosphere slowed down the V–2 from 3,300 to 1,800 miles per hour—and if a missile travels at extremely high speeds, the friction of this dense air produces such high skin temperatures that ordinary metals will melt.

The STRATOSPHERE is the layer of air above the troposphere and ranges in altitude from about 6 to 10 miles to around 40 to 50 miles. In this region temperatures no longer decrease with altitude but stay somewhat constant, and even begin to increase in the upper levels. This higher temperature in the upper portion is caused by a concentration of ozone which is heated by ultraviolet radiation from the sun, and it may reach approximately 170° F. (Ozone is a gas which is produced when electricity is discharged through oxygen.) The composition of the stratosphere is similar to that of the troposphere, however, there is practically no moisture and the winds are relatively steady. Propeller-driven vehicles cannot penetrate this region because of the low density of the air, and airfoils have greatly reduced effect in controlling a missile.

Above the stratosphere and ranging up to about 250 miles is the IONOSPHERE. This is a region rich in ozone and in ionized particles, and consists of a series of electrified layers that envelop the earth. This region is extremely important because of its ability to refract, or bend, radio waves. This property enables a radio transmitter to send waves to the opposite side of the world by a series of refractions and reflections taking place in the ionosphere and at the surface of the earth. The layers of the ionosphere change from daylight to darkness; they vary with the seasons of the year; and they are not identical above all areas of the earth. Little is known about the physical characteristics of this region. Our Armed Forces are continually sending instrument-carrying rockets into it to obtain information about the temperature, the pressure, the composition of the air, and the electrical characteristics of the layers.

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Guided missiles in flight are subject to the laws of aerodynamics, the science that deals with the motions of air and other gases and with the forces acting on solid bodies in motion through these gases. The principles of low-speed aerodynamics, which underlie the operation of most aircraft, also apply to missiles, at least in some phases of flight. But these alone are not sufficient to account for all the effects encountered, since most missiles travel at speeds near sound velocity or greater. Before discussing high-speed flight, however, it is necessary to consider the motions and forces that are common to both guided missiles and conventional airplanes flying at comparatively low speeds.

As a beginning, consider first the motions the missile must perform as it responds to signals from the control system and maintains the proper flight attitude. Like any moving body, the guided missile executes two basic kinds of motions: rotation and translation. In pure rotation, all parts of the body pivot about the center of gravity, describing concentric circles around it. In movements of translation, or linear motions, the center of gravity of the body moves along a line, and all the separate parts follow lines parallel to the path of the center of gravity. Any possible motion of the object is composed of one or the other of these fundamental motions or else is a combination of the two.

Missiles, like other forms of aircraft and like submarines, are free to move in three dimensions. Consequently, to describe their motions, it is necessary to use a reference system containing three separate reference lines, or axes. The missile axes, illustrated in figure 3–5, are three mutually perpendicular lines which intersect at the center of gravity of the airframe. The terms applied to them are identical with those used for other forms of aircraft.

Three kinds of rotary movements can be made by the missile: pitch, roll, and yaw. Pitch, or turning up or down, is a rotation about the lateral axis, the reference line in the horizontal plane running perpendicular to the line of flight. The missile rolls, or twists, about the longitudinal axis, the

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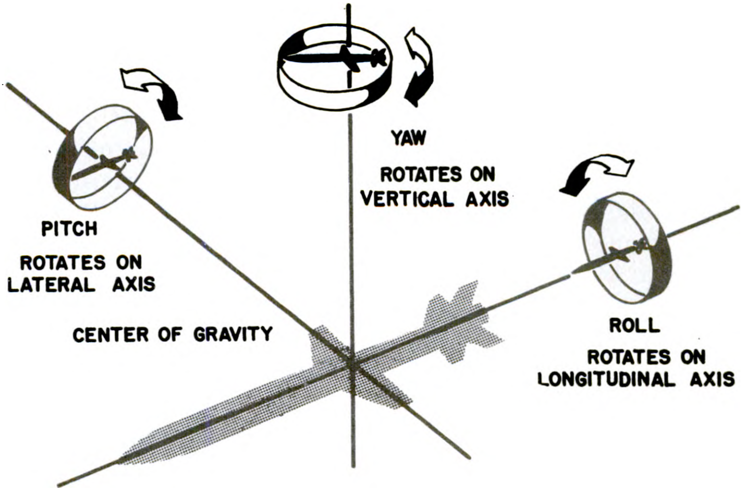

Figure 3–5.—Missile axes.

reference line running through the nose and tail. It yaws, or turns to the right or left, about the vertical axis. Rotary motions about any of the three axes are governed by the steering devices of the missile such as the aerodynamic control surfaces. A fourth motion necessary for control as well as for flight is the motion of translation, the forward movement resulting from the thrust provided by the propulsion system.

Mach Numbers and Speed Regions

Missile speeds are generally expressed in terms of MACH NUMBERS rather than in miles per hour or in knots. The Mach number of any moving body is the ratio of its speed to the speed of sound in the surrounding medium (local speed). For example, if a missile is flying at a speed equal to one-half the local speed of sound, it is said to be flying at Mach 0.5. If it moves at twice the local speed of sound, its speed is then Mach 2. (The term MACH NUMBER is derived from the name of an Austrian physicist, Ernst Mach, who was a pioneer in the field of aerodynamics.)

SPEED OF SOUND.—The speed expressed by the Mach

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number is not a fixed or constant quantity since the speed of sound in air varies with temperature. Sonic speed varies directly with the square root of the absolute temperature (the temperature in degrees centigrade plus 273) of the air, and therefore it is different in different localities. For example, it decreases from 661 knots at sea level (for an average day when the air is 59° F.) to 575 knots at the top of the troposphere. The speed of sound remains constant (with the temperature) from 35,000 feet to 105,000 feet of altitude, then rises to 729 knots, reverses, and falls to 603 knots at the top of the stratosphere. Since the Mach number is the speed of the moving body divided by the speed of sound, it varies inversely with sonic speed. That is, when the speed of sound decreases, the Mach number for a certain speed increases.

The speed of sound is taken as a reference figure for high-speed flight, not because sound is involved directly, but because sound is a series of pressure variations. Its local speed, then, is the rate at which pressure disturbances from a flying body spread out through the air around it. If the missile or other aircraft moves much slower than the pressure waves it causes, the air through which it flies is said to be INCOMPRESSIBLE, that is, air flowing over its surfaces undergoes changes in pressure with little change in density. But as its speed approaches or exceeds the local speed of sound, the airflow is said to be COMPRESSIBLE, and forces are then present which cause this kind of flight to differ considerably from that at low-speed conditions. Thus, the amount of compressibility present depends on the Mach number of the moving body.

REGIONS OF SPEED.—The total range of aircraft speed is divided into three basic regions which are defined with respect to the local speed of sound. These regions are as follows:

1. Subsonic flight, in which the airflow over any surface of the aircraft is less than the speed of sound. The subsonic division starts at Mach 0 and extends to about Mach 0.75. The upper limit varies with different aircraft, depending on the design of the airframe.

2. Transonic flight, in which the airflow over the surfaces

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is mixed, being less than sonic speed in some areas and greater than sonic speed in others. The limits of this region are not sharply drawn, but it is usually considered to extend from about Mach 0.75 to Mach 1.2.

3. Supersonic flight, in which all the airflow over the surfaces of the aircraft occurs at speeds greater than sound velocity. This region extends from the upper limit of the transonic region (about Mach 1.2) upward without limit.

Subsonic Flight

At subsonic speeds, sustained flight by missiles and other heavier-than-air craft is dependent on forces produced by the motion of aerodynamic surfaces through the air. If the surfaces, or airfoils, are well designed, the streams of air flowing over, under, and around them are smooth, conforming to the shapes of the foils. If, in addition, the airfoils are set at the proper angle and if the motion is fast enough, the airflow will support the weight of the aircraft.

FLIGHT FORCES.—The principal forces acting on a missile in level flight are thrust, drag, weight, and lift. Like any other force, each of these is a vector quantity and not only has a magnitude, or amount, but is associated with a par-

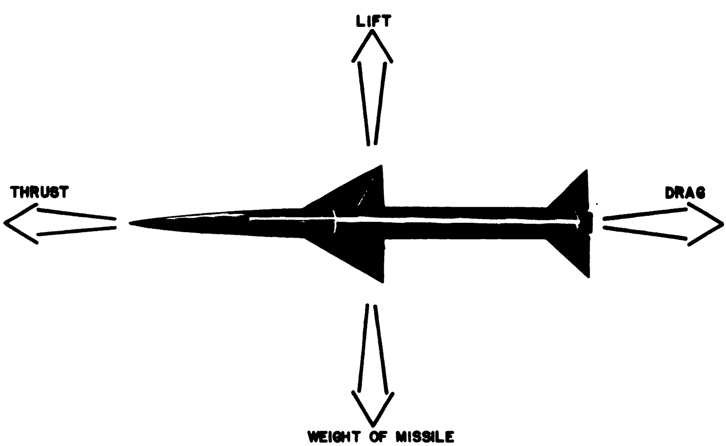

Figure 3–6.—Forces acting on a moving missile.

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ticular direction in space. These forces and their directions are illustrated in figure 3–6.

Thrust, which is supplied by the propulsion system, is directed along the longitudinal axis of the missile and is the force which propels it forward at speeds sufficient to sustain flight. Drag is the resistance offered by the air to the passage of the missile body through it and is directed rearward, acting along the line of the airflow past the airfoil surfaces. The weight of the missile is the force of gravity acting along a line passing through the center of gravity of the body and directed downward toward the center of the earth. Opposed to weight is the lift, the highly desirable force produced by the moving airfoil which supports the body and which is directed perpendicular to the direction of drag.

ACCELERATION.—In level flight at a constant speed, thrust is exactly balanced by drag, and the lifting force exactly cancels the weight of the body. If any one of these basic forces is changed, the result is acceleration. Acceleration in flight is a change, either in speed or in the direction of motion. It occurs in two ways:

1. The aircraft accelerates as it increases or decreases speed along the line of flight. This kind of acceleration takes place in missile flight during launching and also upon impact with the target.

2. The aircraft is accelerated if it changes the direction in which it is moving, for example in turns, dives, pullouts, and as a result of gusts of wind. During acceleration of this sort while in high-speed flight, the aircraft is subjected to large forces which tend to keep it flying along the line of its previous flight.

The standard unit of acceleration used in aviation is the GRAVITY, abbreviated by the letter "g." A body falling freely in space is pulled downward by a force equal to its weight with the result that it accelerates at a constant rate of about 32 feet per second per second. Its acceleration while in free fall is said to be one g. In missiles making rapid turns or while responding to large changes in thrust, the acceleration produced may be many times that of gravity,

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the ratio being expressed as a number of g's. The effect of the force of acceleration on the body is the same as if its weight had been multiplied by a factor equal to the g-value of the acceleration. The number of g's which the missile components can withstand is one of the factors which determine the maximum turning rate and the type of launcher suitable for the weapon, since the delicate instruments of the control and guidance systems may be damaged if subjected to accelerations in excess of a certain value.

PRODUCTION OF LIFT BY AIRFOILS.—Lift, the force on which flight depends, is produced by means of pressure differences. One condition and only one is necessary for the lifting action of a wing to occur: the air pressure on the upper surface must be less than the pressure on the underside. The wing, then, is simply a device for creating pressure differences when in motion. The amount of lifting force provided is dependent to a large extent on the shape of the airfoil, or wing. Additional factors which determine lift are the wing area, the angle at which the wing surface is inclined to the airstream, and the density and relative speed of the air passing around it. The airfoil that gives the greatest lift with the least drag, or retarding force, in subsonic flight has a shape similar to the one illustrated in figure 3–7. The cross section shows a rounded nose, a smoothly arched or cambered top, and a sharp tail.

Some of the standard terms generally applied to airfoils are included in the sketch. The foremost edge of the wing shown at (A) is called the LEADING EDGE, and that at the rear is called the TRAILING EDGE. A straight line drawn between the leading and the trailing edges is called the CHORD; and the

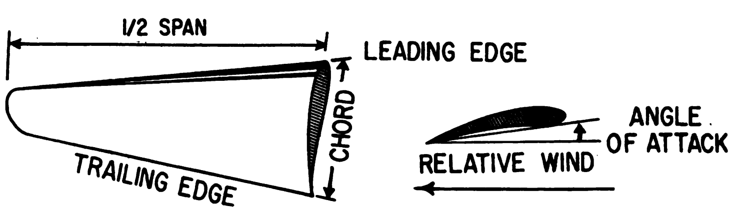

Figure 3–7.—Subsonic airfoil.

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maximum distance measured from one wingtip to the other is known as the SPAN. In (B) of figure 3–7, the arrow symbolizes the RELATIVE WIND, the direction of the airflow with reference to the moving airfoil. In flight, the ANGLE OF ATTACK of a wing is the angle between its CHORD and the RELATIVE WIND.

The relative wind strikes the tilted surface, and as the air flows around the wing different amounts of lifting force are exerted on the various areas of the airfoil. The sum, or resultant, of all these component forces is equivalent to a single force acting at a single point and in a particular direction. This point is called the CENTER OF PRESSURE; and from it the resultant force of lift is directed perpendicular to the direction of the relative wind.

Lift may be considered as resulting from two general causes: One from dynamic pressure, or the pressure of air in motion; and the other from differences in the static pressure of the atmosphere. The dynamic pressure of the relative wind against the underside of the wing accounts for a fraction of the total lift—at most about one-third of it. The remainder is produced by a difference of the static pressures on the upper and lower surfaces. The principal effect is the result of air flowing over the upper wing surfaces with increased velocity and with an accompanying decrease in pressure. The principle involved in the pressure reduction was first announced many years ago by a Swiss physicist, Daniel Bernoulli.

In the form in which it applies to airfoils, Bernoulli's principle is as follows: Air pressure decreases when air velocity increases. This relationship is illustrated in figure 3–8 in the action of the venturi tube, a hollow cylinder containing a constriction, or narrow section, through which a fluid is passing. The rate of flow increases when the fluid passes through the constriction since it must travel a greater distance in following the curved walls of the tube. In this case, the Bernoulli principle says that in the narrow section the pressure exerted laterally against the walls of the tube is less than the lateral pressures on the walls upstream and down-

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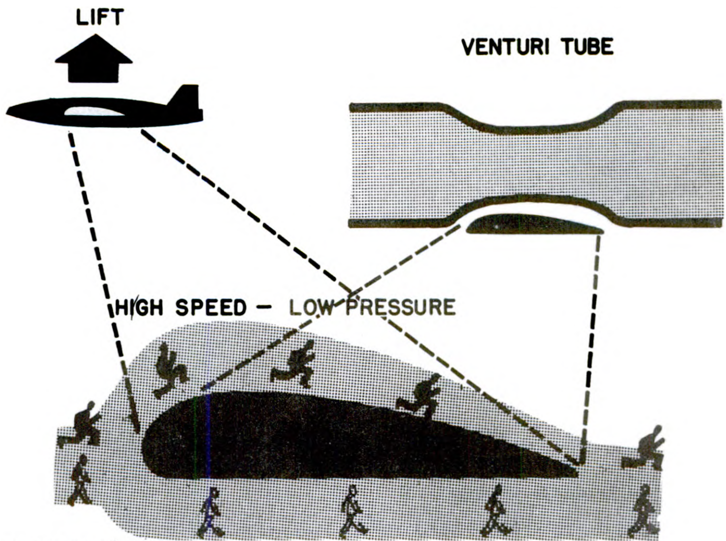

Figure 3–8.—Application of Bernoulli's principle.

stream from this section, and that the difference in pressure results from the increased velocity of flow.

The same relation exists in the streams of air flowing over the upper and lower surfaces of the wing. During flight, part of the approaching air is forced to flow over the longer path of the curved upper area, and its velocity is thereby increased compared with that of the air passing over the shorter path along the underside. The difference in the flow rate causes a difference in the lateral pressures on the two surfaces, and a net force is then present which is directed upward. This force is the greater part of the total lift supporting the weight of the aircraft, the remainder being supplied by the effect of dynamic pressure.

The lift resulting from dynamic pressure is concentrated near the leading edge of the wing in normal flight. The contour of the wing and the angle of attack at which the wing is inclined are such that the airstream is split at a point just under the leading edge. Here the air is forced to change in direction abruptly, and a STAGNATION POINT, or

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high-pressure area is formed. It is important that the design of the wing permits the stagnation point to form on the underside of the leading edge rather than at its center, so that the high-pressure area will increase the total lift instead of merely adding to the drag.

The part that the trailing edge plays in producing lift is illustrated in figure 3–9. The air flowing over the top of the wing joins the airstream from the lower surface at the trailing edge. If this edge were rounded, as in (A) of the figure, the lower stream would curve around to the upper surface and a second high-pressure stagnation point would then form on the top of the wing. Its effect would oppose the lifting force. But if the trailing edge is made sharp, as in (B), the airstream does not make the turn to the topside surface and no undesirable force is produced on the after part of the airfoil.

TURBULENCE AND STALL CONDITIONS.—The whole matter

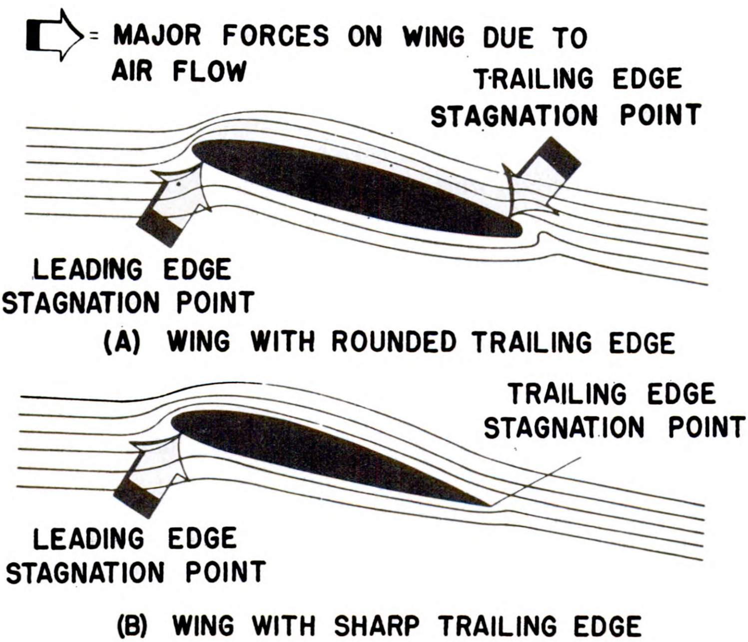

Figure 3–9.—Necessity for a sharp trailing edge.

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of lift is concerned with the smooth flow of air over and under the wing. With this in mind, it is easy to understand what takes place when the aircraft goes into a stall. Up to a point, as the angle of attack is increased, the lift also increases, since the high value of angle causes the air flowing over the upper part of the wing to travel a greater distance. Hence it increases in speed and the pressure difference which produces lift is thereby increased. But if the angle of attack is made too great, lift is destroyed by the formation of turbulence on the upper airfoil surfaces. This condition is shown in figure 3–10.

At moderately high angles of attack, the flowing air can follow the initial turn of the leading edge but it cannot follow the wing contour completely; and the stream separates from

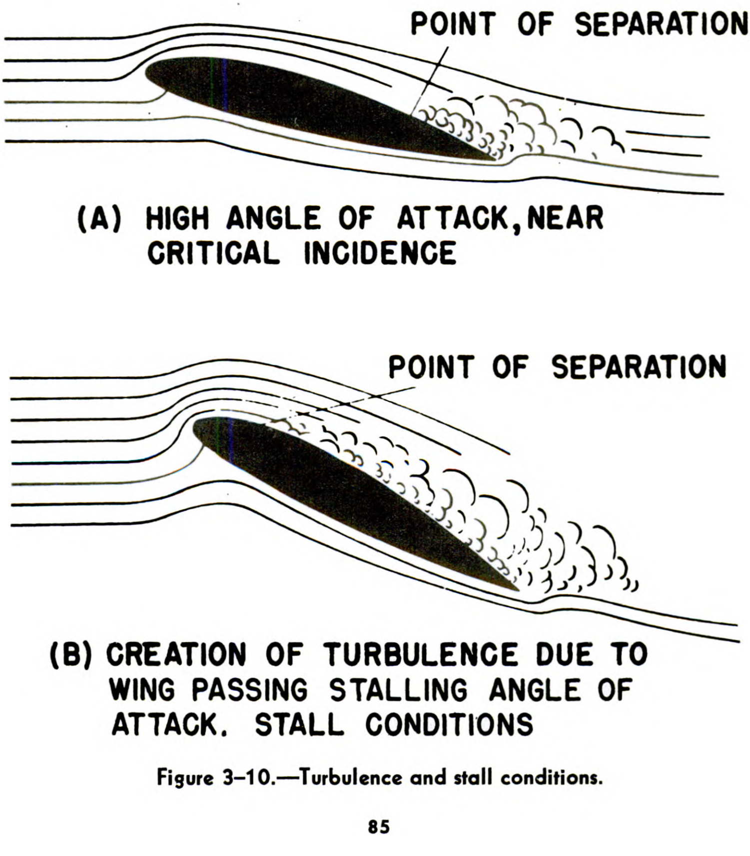

Figure 3–10.—Turbulence and stall conditions.

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the surface near the trailing edge. Further increase of the angle causes the point at which the separation occurs to move forward. At some value of attack angle, the separation point is placed so near the leading edge that the upper airflow is disrupted, flight characteristics disappear, and the wing is in a stall.

Transonic Flight

Control of missiles and jet aircraft in the transonic and supersonic regions differs somewhat from that at subsonic speeds. Particularly in the transonic region the effects are varied, depending mainly on the individual characteristics of the aircraft involved. If the aircraft has been specifically designed for these speeds, the effects are not serious or dangerous. But when aircraft not so designed venture into the transonic speeds, unpredictable and sometimes fatal results may occur. For example, the nose of the aircraft may "tuck down" and the control system may be unable to restore normal flight. In some aircraft, the wings and control surfaces may begin to vibrate violently, or "buzz," upon entering the transonic region. In some cases, the controls become reversed, and the action which usually results in a turn to port may result in one to starboard instead. These effects and many others result from COMPRESSIBILITY, a property of the airstream which is not prominent at low speeds but which cannot be ignored as the airspeed progressively increases.

It is important to remember that air, like any other gas, is compressible regardless of speed; and compressibility is not something which suddenly appears. But it is rather something which builds up with increasing speed so that it is principally in transonic flight that it is capable of causing the effects mentioned above.

THE NATURE OF COMPRESSIBILITY.—When an object moves through the air, it continuously produces small pressure disturbances in the airstream as it collides with the air particles in its path. Each such disturbance—a small variation in the pressure of the air—is transmitted outward in the form of a weak pressure wave. Each expanding

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pressure wave travels at the speed of sound since sound waves in themselves are nothing but pressure variations. Although each pressure wave expands equally in all directions, the important direction is that in which the object generating it is moving. This is true because the pressure wave effectively serves as an advance warning to the air particles in the path of the object, informing them that the object will soon be moving through.

As long as the object is moving at a low subsonic speed, its position in space with respect to a pressure wave it produces is similar to that shown in (A) of figure 3–11. The pressure wave expands in all directions; and since its speed is high compared with that of the body, the variation in pressure travels well ahead and agitates the air particles in the path of motion. Hence, when the body arrives at any given point, the air particles there are already in motion and can easily and smoothly conform to its shape and flow around it.

In (B) and (C) of the figure, the object is represented as increasing in speed but as still traveling below the sonic velocity. As its speed increases, the object at any moment is situated proportionately nearer the undisturbed air particles in its path. This means that the greater the speed of the moving body, the fewer the number of air particles that will be able to move from its path, with the result that the air begins to pile up in front of the body.

When the object reaches the speed of sound, the condition represented in (D) of figure 3–11 occurs. The pressure wave can no longer outrun the object and prepare the air particles in the path ahead. The particles then remain undisturbed until they collide with the air that has piled up in the airstream just ahead of the object. As a result of the collision, the airstream just ahead of the object is reduced in speed very rapidly; while at the same time, its density, pressure, and temperature increase.

As the speed of the object is increased beyond the speed of sound, the pressure, density, and temperature of the air just ahead of it are increased accordingly; and a region of highly compressed air extends some distance out in front of the body.

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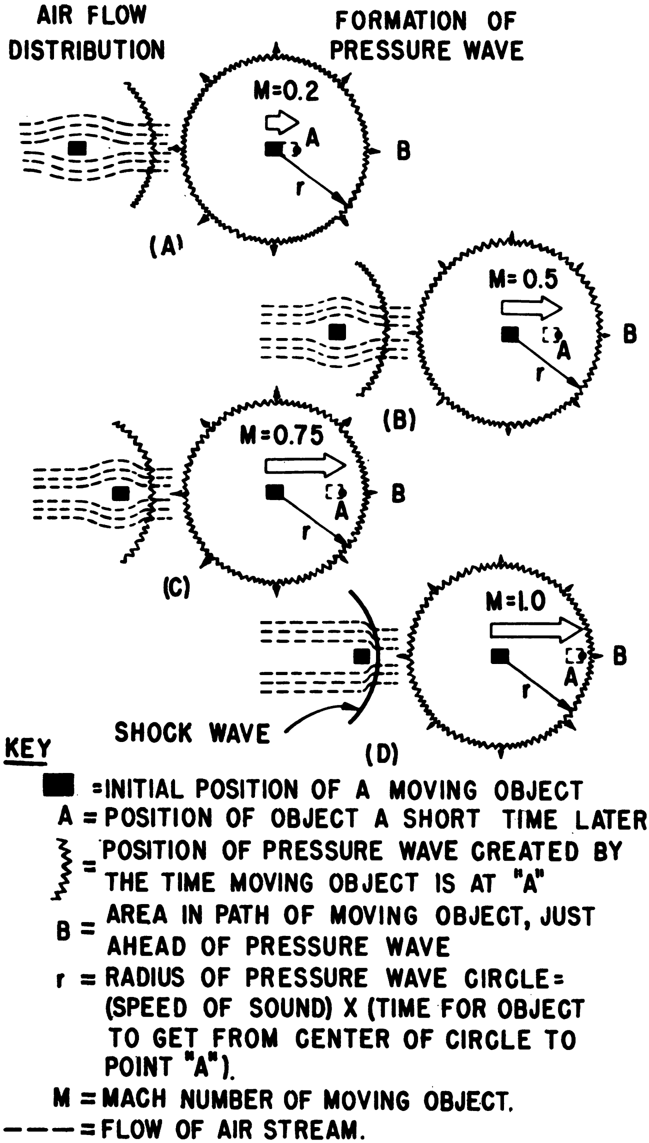

Figure 3–11.—Compressibility at various speeds.

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Thus a situation occurs in which the air particles forward of the compressed region at one moment are completely undisturbed, and at the next moment are compelled to undergo drastic changes in velocity, density, temperature, and pressure. These abrupt changes occurring in the airstream are illustrated by the graph shown in figure 3–12. Because of the sudden nature of the transition, the boundary between the undisturbed air and the compressed region is called a SHOCK WAVE.

In summary, the following can be said concerning the nature of compressibility and its effects: The greater the speed of a blunt body moving through air, the greater is the air density and air pressure directly in front of it, and the

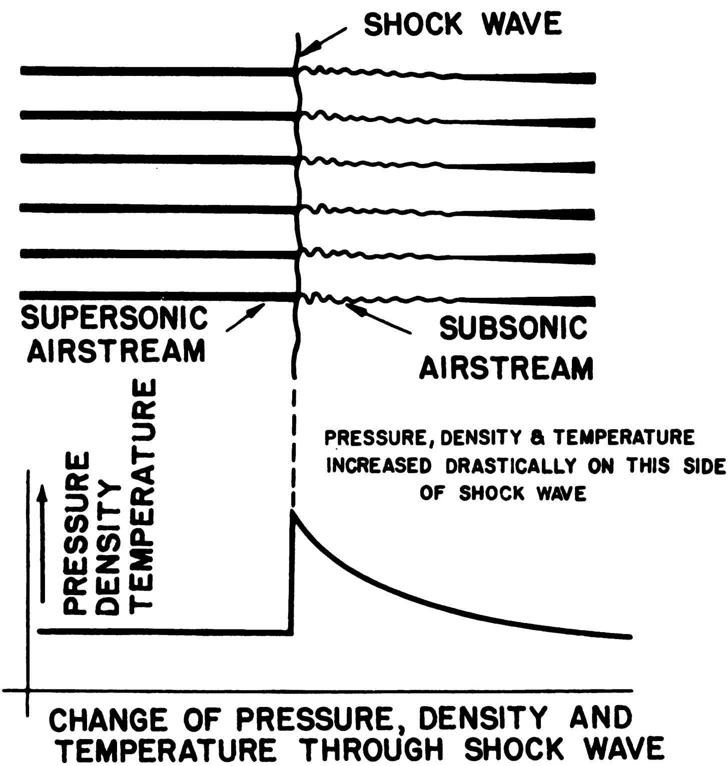

Figure 3–12.—Physical changes occurring in a shock wave.

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less smooth is the flow of air around it. At comparatively low speeds, the density changes of the air due to its compressibility can be ignored. But at airspeeds of about Mach 0.3, the density changes begin to be increasingly important. In general this effect is an aid to lift until the airstream at any point on the wing surface exceeds the speed of sound. When this happens, sudden changes in the conditions of the air take place due to the formation of shock waves.

SHOCK WAVES.—There are several types of shock waves, the principal classes being the NORMAL and the OBLIQUE. These two differ primarily in the way in which the airstream passes through them. In the normal (or perpendicular) wave, the air passes through without changing in direction, and the wavefront is perpendicular to the line of flow. The normal shock wave is usually very strong, that is, the changes in pressure, density, and temperature within it are great. The air passing through the normal shock wave always changes from supersonic to subsonic velocity.

Oblique shock waves are those in which the airstream changes in direction upon passing through the transition marked by the wavefront. These waves are produced in supersonic airstreams at the point of entry of wedge-shaped and other sharply pointed bodies; and the resulting wavefronts make angles of less than ninety degrees with the axis of motion. Like the normal shock wave, the oblique wave occurs at a point of change in velocity from a higher to a lower value. The change in speed is usually from high supersonic to low supersonic, but in some cases the airflow is supersonic upstream and subsonic downstream of the oblique wave. In general, the variations in density, pressure, and temperature are less severe in the oblique wave than in normal shock waves.

Normal shock waves can be formed in different ways. They occur when blunt objects are placed in supersonic airstreams. They can also form in airflow which contains no interfering object, provided the air makes rapid changes in velocity, an example being the flow in a venturi tube. In a similar manner, normal shock waves can occur over the wing surfaces of a subsonic aircraft that exceeds its maximum safe

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operating speed. In this case, the formation of the shock wave is illustrated in figure 3–13.

In the figure, the high-speed (but still subsonic) airstream flows up over the leading edge of the wing, increasing in velocity as it does so, and passes the speed of sound. At a point on the wing slightly rearward of the leading edge, the velocity of the flow decreases, changing from supersonic to a subsonic value. At the point of transition, a normal shock wave is formed. This process illustrates the following rule which always holds true:

"The transition of air from subsonic to supersonic flow is always smooth and unaccompanied by shock waves; but the change from supersonic to subsonic flow is always sudden and is accompanied by large variations in pressure, density, and temperature. These variations take place at the point of formation of a shock wave."

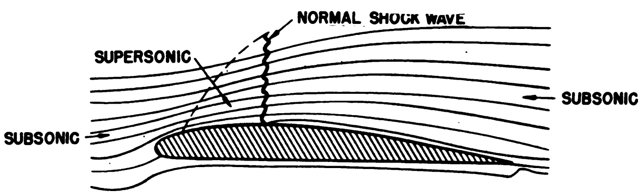

Figure 3–13.—Formation of normal shock wave on airfoil.

Figure 3–13 shows the formation of a shock wave on the airfoil of an aircraft flying just fast enough to cause supersonic flow over the top of the wing. If the speed of the air is further increased, the conditions illustrated in figure 3–14 are present. The area of supersonic flow increases, and the shock wave moves back toward the trailing edge. In addition, supersonic airflow develops below the wing, and a shock wave also forms there at the point at which the airflow is reduced to subsonic speed. Finally, when the wing itself reaches supersonic speed, the upper and lower shock waves move all the way back to the trailing edge; and at the same time, a new shock wave is produced in front of the leading edge.

Attached and detached shock waves.—The shock wave formed on the leading edge of the wing shown in

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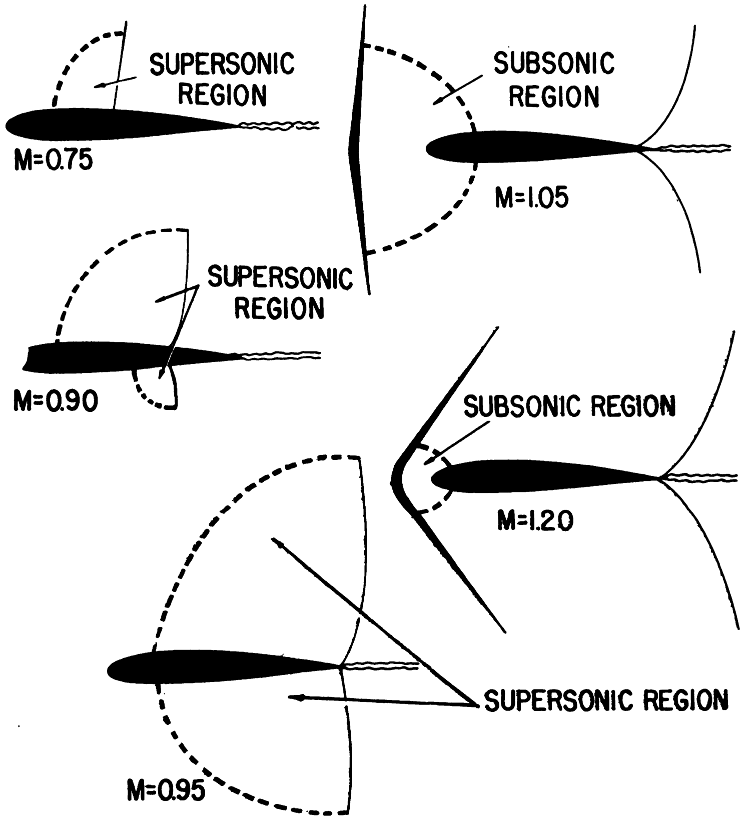

Figure 3–14.—Shock waves on airfoil at various speeds.

figure 3–14 is separated from the entering surface by a small area of subsonic air, like the wave produced in front of the blunt object discussed earlier. When the shock wave is separated from an object in this way, it is said to be DETACHED. When first formed, the detached shock wave lies in a plane perpendicular to the airflow. As the speed of the object is increased, the shock wave bends toward it, forming what is known as the MACH CONE. The sharpness of the Mach cone depends on the shape of the object, and is also an indication of the speed of the surrounding airstream. The cone is sharper for wedgelike or pointed

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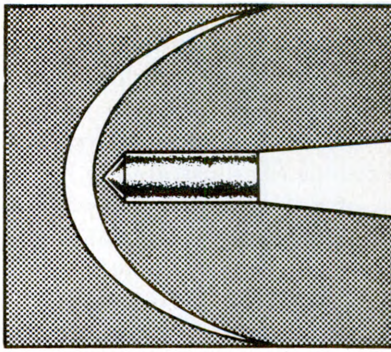
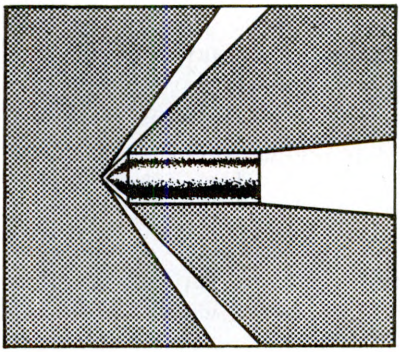
(A)

DETACHED SHOCK WAVE M=1.9





(B)

ATTACHED SHOCK WAVE FORMED BY INCREASING SPEED TO M=2.5

(C)

ATTACHED SHOCK WAVE FORMED BY CHANGING SHAPE OF OBJECT (SPEED STILL ONLY M=1.9)

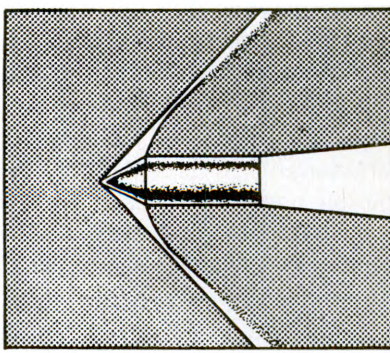


Figure 3–15.—Detached and attached shock waves.

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objects than for blunt shapes, and it grows increasingly pointed as the speed increases.

Under the right conditions of airspeed and object shape, the shock wave forms on the object itself and is then said to be an ATTACHED SHOCK WAVE. The effects of these conditions are illustrated in figure 3–15. In (A), the formation of a detached shock wave is shown. When the speed of the object increases, the Mach cone becomes sharper and the attached shock wave (B) is formed. The same situation can be achieved by increasing the sharpness of the object, as shown in (C).

COMPRESSIBILITY EFFECTS OF SHOCK WAVES.—Unless the aircraft is designed so that the effects of compressibility are eliminated, many undesirable actions may take place. When normal shock waves appear on the wings, they tend to move toward the trailing edge if the speed of the aircraft is increased, and separation of the airstream occurs immediately behind the shock wave. That is, the air cannot continue to follow the desirable flow pattern normally produced by the wing surface. As a result, the airflow tumbles in a random, turbulent motion. When turbulence starts to grow, it makes itself felt in certain ways. For example, rolling motion of the aircraft may result from small differences in wing construction that would be unnoticed at low speeds. Also rapid vibrations of the ailerons may occur; and noticeable twisting of the wings may take place.

To avoid these effects, the airframe design of high-speed guided missiles and jet aircraft exhibits several general characteristics. The airframe is provided with a sharp, tapering nose section, and the body is constructed so that there are few if any abrupt changes in contour at which normal shock waves might form. The control surfaces are placed so as to be free as possible of the turbulence produced by the lifting surfaces—in some cases the control actions are accomplished by moving the entire wing.

Wings and control surfaces are very thin and have knife-like edges. This both reduces drag and causes the shock waves that are formed at the leading edges to be of the oblique type. In these the variations in pressure and density are

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less severe than in normal shock waves which would occur with blunt edges.

Wings for high-speed craft are usually sweptback rather than straight. They have low aspect ratios, the ratio of span to average chord length, thereby presenting a very short and stubby appearance. Several cross section patterns are employed, including the diamond shape, or double wedge, and the biconvex, the latter being the pattern formed by the intersection of two circular arcs. (The characteristics of the various airfoils in use are discussed in a later section.)

Supersonic Flight

Once out of the transonic speed region, the upper limit of which is about Mach 1.2, the airflow over any area of the aircraft is supersonic in velocity. In this condition, the undesirable effects of mixed supersonic and subsonic flow largely disappear, and the passage of air over the airframe surfaces is without turbulence. The variations in pressure which occur are of two principal kinds: compression waves of the oblique shock wave type, and EXPANSION WAVES.

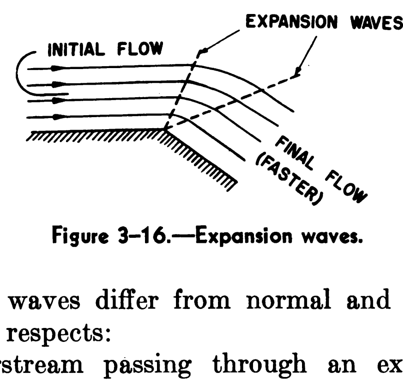

Figure 3–16.—Expansion waves.

Expansion waves differ from normal and oblique shock waves in two respects:

1. The airstream passing through an expansion wave increases in velocity. It undergoes a corresponding decrease in temperature, density and pressure.

2. The increase in velocity of the airstream passing through the expansion wave is gradual rather than sudden.

LIFT FOR SUPERSONIC AIRCRAFT.—In the section on subsonic flight, the broad general principles of producing lift

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by cambered wings were pointed out. The thin symmetrical wings used in supersonic flight deserve further explanation because the sharp leading edges employed at these speeds do not produce the same deviation of airflow as the round-nose counterpart.

The thin wing illustrated in figure 3–17 provides lift by means of pressure differences depending on oblique shock waves and expansion waves. The oncoming airstream is deflected by the sharp edge, and then assumes a direction parallel to the wing. On the upper wing surface, the air is speeded up by passing through a series of expansion waves with the result that a low-pressure area is formed on the top of the wing, much as in subsonic flow.

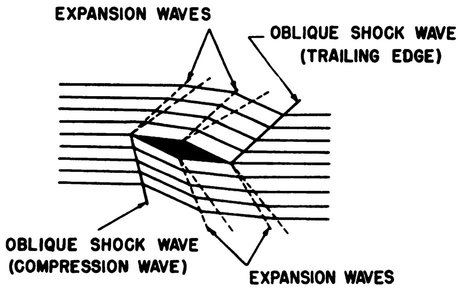

Figure 3–17.—Airflow about supersonic wing.

Beneath the wing, the force of the airstream (the dynamic pressure), together with the changes occurring in passing through an oblique shock wave, results in the formation of a high-pressure area. As in subsonic flow, the difference in pressures on the upper and lower surfaces of the wing results in an upward lifting force.

FLIGHT CONTROL

Missile flight control includes all the processes of attitude and path control. The final process of control, called steering, puts the directing signals into effect by the application of some force which will turn the missile about one of its three axes. This force may be produced by one or more of the following: Airfoils, jet vanes, or side jets.

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Airfoils are used to provide stability and control of most air-launched missiles. The shape—the pattern of the cross section—of the airfoil employed is determined largely by the speed of the missile. Some of the basic patterns are shown in figure 3–18. The contour of subsonic airfoils is similar to that of the conventional aircraft wing, but those used on supersonic missiles are much thinner.

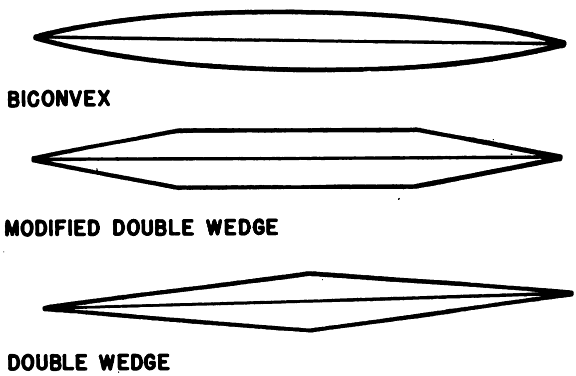

Figure 3–18.—Supersonic airfoil cross sections.

The airfoils used for supersonic flight are symmetrical in cross section and have a small thickness ratio—the ratio of the maximum thickness to the chord length. The DOUBLE WEDGE in the figure has the least drag for a given thickness ratio, but in certain applications it is inferior because it lacks the necessary strength. The MODIFIED DOUBLE WEDGE has a relatively low drag (although its drag is usually higher than a double wedge of the same thickness ratio) and is stronger than the double wedge. Ease of manufacture and good overall performance characteristics make this airfoil the best of presently-known configurations. The BICONVEX, also shown in the figure, has one and one-third greater drag than a double wedge of the same thickness ratio. It is the strongest of the three types shown, but it is difficult to manufacture.

The planform of the airfoils—the outline when viewed

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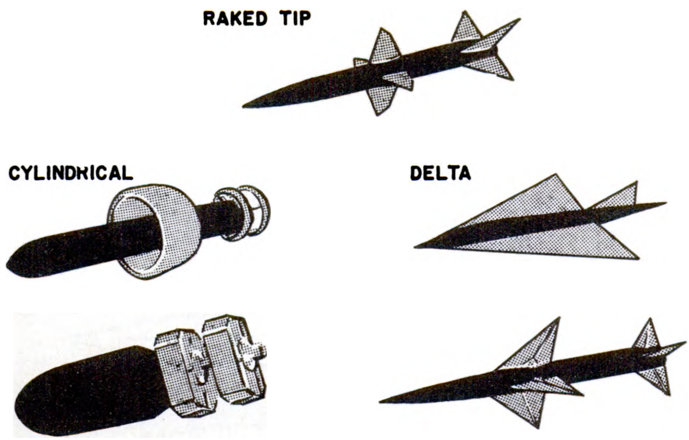

Figure 3–19.—Airfoil planforms.

from above—may be one of the basic types shown in figure 3–19. As mentioned previously, travel in the transonic and supersonic regions is accompanied by shock waves. With the conventional wing plan, which presents its leading edge perpendicular to the direction of motion, shock waves occur at lower speeds than if other planforms are used. The presence of these shock waves on an airfoil greatly increases the drag and subjects the airfoil to extreme stresses. To reduce the effect of these undesirable features, airfoils for transonic and supersonic flight are built in the shape of an arrow or the Greek letter "delta" (Δ) and are swept back or forward. Two types of DELTA planforms and a modified delta, the RAKED TIP, are shown in the figure. The CYLINDRICAL arrangements in the figure were used on the *Roc* and *Razon* missiles of World War II.

Airfoils are mounted on the airframe in several arrangements, some of which are shown in figure 3–20. The CONVENTIONAL and CRUCIFORM are the most popular tail arrangements; and the HIGH WING and CRUCIFORM WINGS are used for most air-launched missiles. Both the INLINE and INTERDIGITAL cruciform arrangements are widely used, especially for supersonic missiles.

The two methods of using airfoils to steer a missile are

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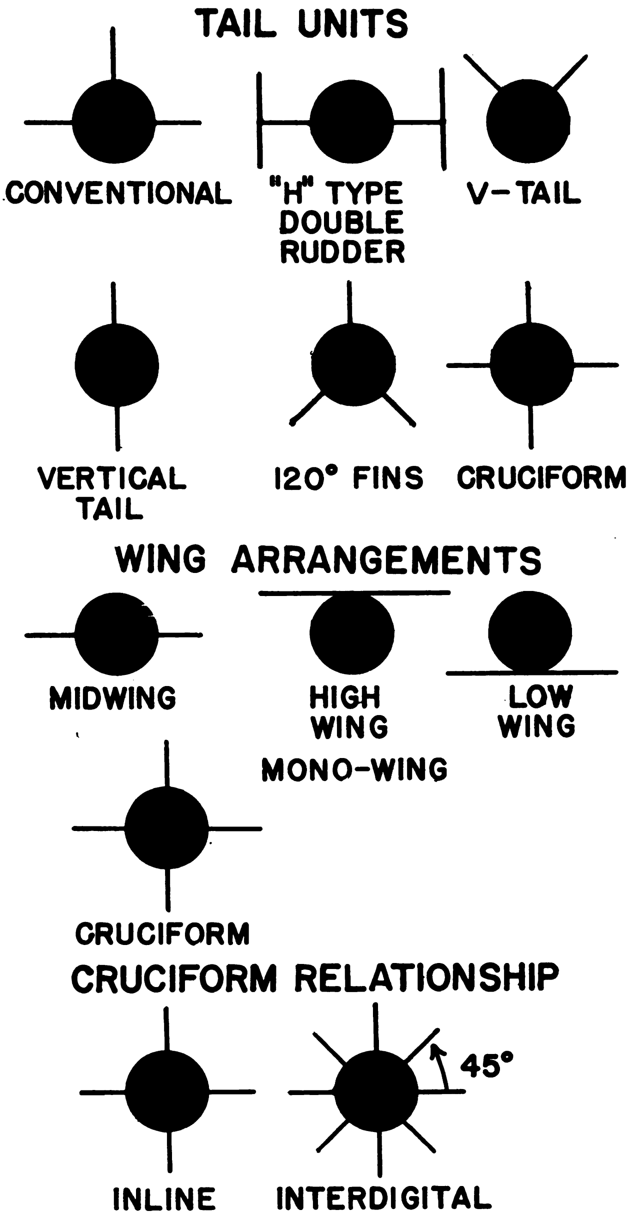

Figure 3–20.—Arrangements of airfoils.

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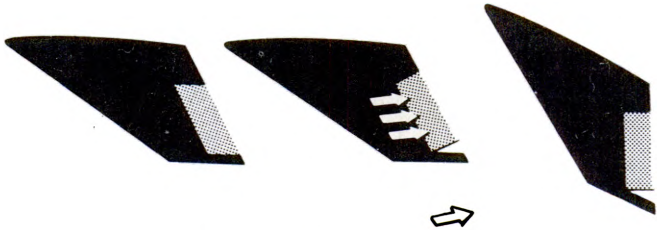

Figure 3–21.—Airfoil control methods.

shown in figure 3–21. In (A) of the figure, the airfoil contains a movable section called a CONTROL SURFACE which is deflected so that the force of the airstream turns the missile. In the other method, shown in (B) of the figure, the entire airfoil is deflected. This type requires less movement to produce the necessary turning force, but as a result a very accurate power unit is required to control its motion. Because the airfoils required by subsonic missiles are very large in comparison with those used for supersonic speeds, it is difficult to move the entire airfoil. For this reason, movable sections are used for control of most low-speed missiles. In some cases, the movable sections contain a small control surface, called a TRIM TAB, which is adjusted manually on the ground to compensate for any unbalance or misalinement of the main control surfaces.

Control surfaces are placed on the missile at several locations to provide different types of steering. In the conventional aircraft arrangement, shown in figure 3–22 (A), movable sections of the tail airfoils control pitch and yaw, and control surfaces on the wings control roll. Movement of the RUDDER causes the missile to turn about its yaw axis; the ELEVATORS are moved together to make the missile pitch; and the AILERONS are moved in opposite directions to make it roll. In the cruciform arrangements, shown in (B) and (C) of the figure, pitch is controlled by moving the horizontal surfaces together; yaw is controlled by moving the vertical surfaces together; and roll is accomplished by deflecting either the pitch or yaw surfaces in opposite directions. If the forward set of airfoils is fixed, and steering is

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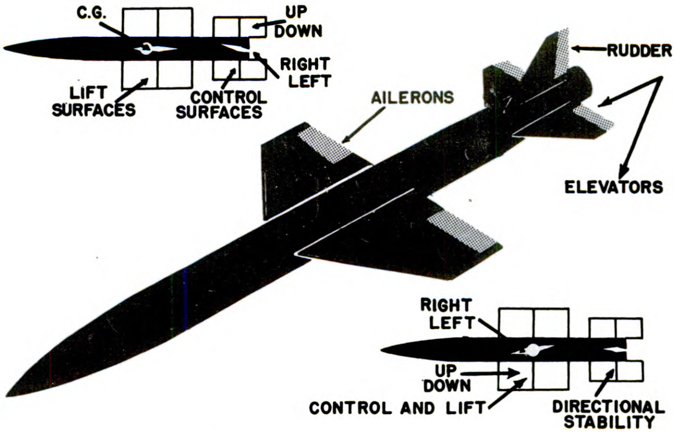

Figure 3–22.—Control surface locations.

accomplished by the tail surfaces as shown in (B) of the figure, the missile is said to be "tail" controlled. Another type is "canard" control, illustrated in (C) of the figure, in which the tail fins are fixed and control is provided by the forward surfaces. Other arrangements, such as the one shown in (D) of the figure, may also be used. In the one shown, pitch and yaw are controlled by the forward wings and roll by one pair of tail surfaces.

Airfoil control works efficiently while the missile is in the atmosphere. However, it requires a missile velocity that will create enough air pressure on the surfaces to cause the missile to turn. When the missile moves very slowly or reaches highly rarefied atmosphere, the forces which the control surfaces develop are too low to change the path of the missile. When this happens, it is necessary to use some form of jet steering, such as jet vanes or side jets.

Jet Vanes and Side Jets

Jet vanes are similar to airfoil control surfaces in design, but are smaller and are placed in the jet stream of the motor. When moved, these surfaces deflect a portion of the jet gases so that the line of thrust is not directly through the center of gravity of the missile. This causes the missile to turn.

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One disadvantage of this method of steering is that the average life of the jet vanes is very short because they are burned out by the tremendous heat from the jet stream. The jet vanes used in the German V–2 lasted, on the average, about sixty seconds. This disadvantage may be overcome by the use of several jet motors which are permanently offset, or fixed on the sides of the missile. Jets which are used in this manner to steer the missile are called SIDE JETS. The main requirement of this method of controlling the flight path is that the jets be capable of being turned on and off rapidly. The turning forces side jets develop remain constant regardless of flight conditions.

Airspeed and Air Density Corrections

When airfoils are used as steering devices, it is necessary to adjust their deflections so that the turning forces they produce will remain constant for varying flight conditions. This is because the lift produced by an airfoil is proportional to the speed and density of the air passing over it, as well as to the angle of attack. At high speeds, or low altitudes where the air is denser, less movement of the control surfaces is required to turn the missile than at low speeds or higher altitudes.

In some control systems, the amount of response made by the control surfaces is made dependent upon a signal derived from a pressure gage. This pressure gage measures the dynamic pressure of the airstream which is determined by the velocity of the missile and the density of the air. High speed and high air density produce a high dynamic pressure, and under these conditions the amount of deflection of the control surfaces necessary for a maneuver is decreased.

In other control systems the power units automatically adjust the response of the control surfaces to flight conditions. With these units, the surfaces are not moved an AMOUNT proportional to the directing signal, but are moved until they produce a FORCE proportional to the signal.

In summary, the purpose of this correction is to keep the missile response constant under varying conditions of flight.

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Roll Control

One of the main functions of most control systems is that of ROLL CONTROL—the process of controlling missile motion about the longitudinal axis. Some missiles must remain in a fixed position, while others require a certain amount of roll for efficient steering. This control is usually accomplished by the use of a gyroscope.

The rotating gyroscope wheel has the property of maintaining its original orientation in space as long as no external torques are applied to disturb it. When suitably mounted on gimbal rings, it is used to indicate the angle of roll of the missile with respect to the original setting of the gyroscope axis. If a missile which must remain in a fixed position should happen to roll, signals are obtained from electrical devices on the gyroscope. These signals are sent to the power units to cause the missile to return to its original position. If roll is desired, signals are sent to torque producing devices on the gyroscope so that it moves to a new orientation. As the gyroscope moves, signals are developed by the electrical devices and are sent to the power units to cause the missile to roll the desired amount.

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QUIZ

1. The density of the atmosphere changes most rapidly in the
    a. ionosphere
    b. stratosphere
    c. troposphere
    d. E-layer

2. The "jet stream" is formed in the
    a. upper stratosphere
    b. lower ionosphere
    c. upper ionosphere
    d. upper troposphere

3. The Mach number for a given speed varies
    a. directly with sonic speed
    b. directly with the square root of sonic speed
    c. inversely with sonic speed
    d. inversely with the square root of sonic speed

4. Sonic speed varies directly with the square root of the
    a. temperature in degrees centigrade
    b. absolute temperature
    c. pressure above sea level
    d. absolute pressure

5. When air passes through a normal shock wave it changes from __________ velocity.
    a. subsonic to supersonic
    b. supersonic to subsonic
    c. subsonic to transonic
    d. supersonic to transonic

6. Between the chord of an aerodynamic surface and the relative wind is an acute angle known as the
    a. chord angle
    b. surface angle
    c. angle of attack
    d. relative wind angle

7. With the same amount of thrust applied, a rocket would fly faster in the
    a. lower stratosphere
    b. lower ionosphere
    c. upper stratosphere
    d. upper troposphere

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8. At the time a guided missile passes through what is commonly called the sound barrier, it is in the __________ speed zone.
   a. subsonic
   b. transonic
   c. supersonic
   d. hypersonic

9. A rocket-propelled guided missile ascending from the earth's surface would experience less drag as it passed through the
   a. atmosphere
   b. stratosphere
   c. ionosphere
   d. troposphere

10. The region of atmosphere around the earth that has steady winds, relatively constant temperature, and contains very little moisture is known as the
    a. ionosphere
    b. stratosphere
    c. troposphere
    d. outer ionosphere

11. Speeds within the transonic speed zone are considered to be between __________ Mach.
    a. 0 and 0.75
    b. 0.75 and 1.2
    c. 1.2 and 4.0
    d. 4.0 and 10

12. The height of the earth's atmosphere is approximately __________ miles.
    a. 10
    b. 50
    c. 60
    d. 250

13. Which of the atmospheric regions accounts for the largest portion of the atmospheric weight?
    a. Troposphere
    b. Ionosphere
    c. Stratosphere
    d. E-layer

14. Which of the following airfoils usually has the least drag?
    a. Biconvex
    b. Double wedge
    c. Modified double wedge
    d. Conventional

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15. Which of the following airfoil arrangements is the most popular for air-launched missiles?
   a. Cruciform
   b. Conventional
   c. H-type
   d. 120-degree fins

16. Which of the following is a disadvantage of jet vane control?
   a. Weight
   b. Overcontrolling
   c. Altitude limitations
   d. Short life of the vanes

17. Air is considered to be incompressible when a moving body
   a. moves faster than the pressure wave it causes
   b. moves slower than the pressure wave it causes
   c. moves faster than Mach 1
   d. causes great changes in the density of the air flowing over its surface

18. Lift of an airfoil is produced by means of
   a. speed
   b. angle of attack
   c. density of the air
   d. pressure differences

19. If, in an airstream, we have a gradual increase in velocity with a corresponding decrease in temperature, density, and pressure a/an __________ wave is formed.
   a. normal shock
   b. oblique shock
   c. detached
   d. expansion

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CHAPTER 4

AIR-LAUNCHED GUIDANCE EQUIPMENT

One of the essential characteristics of the guided missile is the use of electromechanical systems for carrying out the actions of guidance and control—the processes that are performed by the pilot in conventional aircraft. By automatic action, the missile then becomes a projectile which is able to correct its path as it flies toward the target; and by compensating for inaccuracies in aiming and for evasive motions of the victim, its probability of striking and destroying the enemy object is greatly increased.

The four basic processes in missile guidance and control are TRACKING, COMPUTING, DIRECTING, and STEERING. In flight, the vehicle is steered by means of movable wings, by movable or controlled thrust jets, or by other kinds of devices which are actuated by the control system, or autopilot. Most control systems contain sensing instruments, such as gyroscopes, which detect deviations in the attitude and direction of the missile, and also servomechanisms, which adjust the airfoil surfaces. By these means, the missile is maintained in stable flight. That is, the axes of pitch, yaw, and usually of roll, are properly inclined to some reference plane, such as the surface of the earth or an arbitrary plane in free space.

The autopilot causes the flight path to lie along a straight line until it receives a signal from the components of the guidance system, indicating that an error is present in the heading. The response of the circuits of the autopilot makes adjustments to the control surfaces in such a way that the flight path is altered until the proper flight attitude is attained.

The guidance system consists of the components which

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supply the error signals, which are derived by tracking and/or computing. In the tracking operation, the target is kept under constant observation, and its position relative to the missile is continuously determined. This action supplies data from which the desired path from the missile to the target can be computed or otherwise found. From the computations, the appropriate error signals are developed and applied to the input of the control system to complete the process of directing.

The four basic actions of guidance and control are illustrated in the case of a simple radar system in figure 4–1. To perform its tasks satisfactorily, it would be desirable for the guidance system to be capable of tracking the target in spite of any countermeasures which the enemy can be expected to employ. A missile that would remain unconfused by jamming emissions and undeceived by camouflage or by false targets such as "window," or by the distracting receptions from the ground or sea called "clutter," would constitute an ideal theoretical system.

The various methods of guidance employed in the general field of guided missiles can be classified under the major

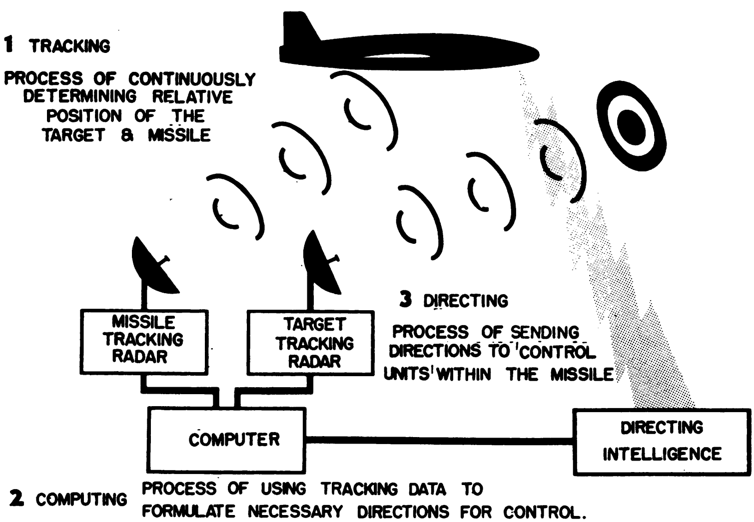

Figure 4–1.—Processes of guidance and control.

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headings listed in chapter 2, which also contains a description of each method. These are the SELF-CONTAINED, BASELINE, BEAM-RIDER AND COMMAND, and HOMING systems. The selection of one of these methods for application in a particular missile is influenced by the following factors: (1) the type of target against which the missile is to be used, (2) the effective range of the missile, (3) the number of corrections which must be applied during flight, (4) the nature and location of the launching equipment, and (5) the "visibility" of the target, that is, whether the total flight path lies within the line-of-sight distance to the horizon or whether its extent is great enough to make the curvature of the earth a necessary consideration.

It is the purpose of this chapter to serve as an introduction to the guidance systems employed in air-launched missiles, the principal types of which are illustrated in figure 4–2. In operations involving these weapons, the target is usually located at a distance from the launching site which is short compared with the distance over which a typical surface-to-surface missile travels. In most cases, the target is relatively small and is often highly maneuverable; and generally, it

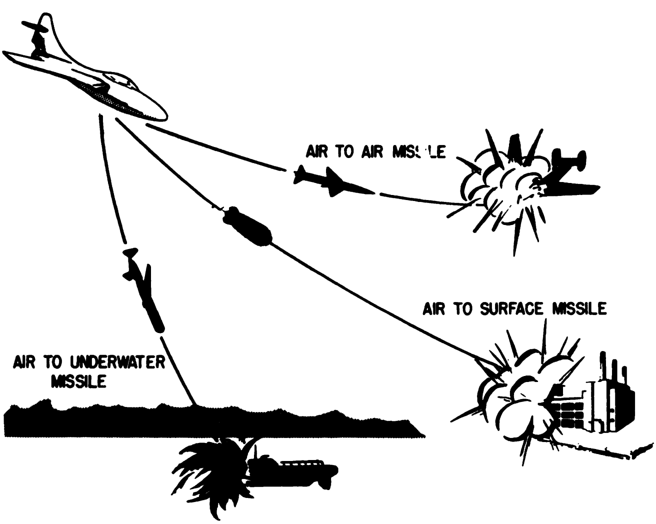

Figure 4–2.—Types of air-launched missiles.

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lies within the line-of-sight distance to the horizon. Because of these considerations, a guidance method is required that is capable of making continuous correction of the flight path and which can respond rapidly to changes in the position of the target. Suitable guidance systems must be adapted for firing from maneuverable launchers, since air-launched missiles may be carried either on pylons attached to the wings of the aircraft or on some enclosed or retractable mechanism.

The aircraft may be maneuvered so as to point the missile in the direction of the target or in a direction which would cause it to lead the target to a point of collision.

The guidance methods most suitable for these conditions are the beam-rider, the homing systems, and in some cases the command method; and it is to these that the following discussion is confined. The other guidance methods, such as the self-contained and baseline systems (see ch. 2), are more suitable for long-range missiles and find limited application in naval air-launched systems.

In the operation of the beam-rider system, the target is tracked by some sort of beam—usually that of a radar set carried by the launching aircraft—and the missile responds to the beam by means of a receiver. The output of the receiver consists of the error signals which, when applied to the control mechanism, cause the vehicle to remain in the center of the beam until collision with the target. With command guidance, the target and the missile are tracked independently, and the missile flight path is computed from the two sets of data. The necessary flight path orders are then transmitted to the missile, which is maneuvered in accordance with these command signals.

Homing systems operate by detecting some distinguishing emission from the target, such as radiant heat, radar or radio waves, or visible light. The guidance equipment carried by the missile may or may not originate the emission by which the target is detected. In some cases (semiactive homing), the target is illuminated by some type of energy (usually radar) originating at the launching aircraft, and the missile homes on the echoes returned by reflection. In others

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(active homing), the illuminating source is carried in the missile; while in a third type (passive homing), the missile receives natural radiations from the target and is independent of any other source of signals.

RADAR APPLICATIONS IN MISSILE GUIDANCE

Because of the great importance of radar in the systems mentioned above, it is necessary to consider several fundamental radar techniques which are characteristic of missile guidance before describing any of the specific systems. Before reading the present section and those which follow, the reader should study carefully the material contained in chapter 14 of *Basic Electronics*, NavPers 10087, which is concerned with the general principles and concepts of radar and with the basic types of radar circuits and components.

Types of Missile Radar

The radar equipments used in missile systems operate by one of the three methods listed in the basic text: PULSE MODULATION, CONTINUOUS-WAVE (c-w), and FREQUENCY MODULATION (f-m). Of these, perhaps the method most frequently employed is pulse modulation, in which pulses of very short time duration are transmitted and received. These electromagnetic radiations are situated in the microwave region of the spectrum to permit the formation of narrow beams with small antennas, and also to allow the use of small components in the system. Missile pulse equipment usually operates by emitting a comparatively high number of pulses per second (pulse repetition frequency), each of which is of very short time duration, or pulse width. These characteristics, together with the formation of narrow beams of radiation, insure accuracy in range and angle measurements and are necessary for good resolution, or the ability to distinguish two targets which are very near each other.

The primary function of a c-w radar is to transmit a continuous signal and to receive from the target a reflected signal which is shifted in frequency. The amount of frequency

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change, called the DOPPLER FREQUENCY, depends on the velocity with which the missile moves toward or away from the target object; and this value can be measured by a suitable detector to indicate the presence of a moving object and to reveal the closing speed of the missile with respect to it. Two antennas are usually employed in c-w systems. In most missile applications, one antenna receives radar waves directly from the launching aircraft's radar transmitter. The other antenna receives reflections from the target, which is illuminated by the emissions from the parent radar. The signals are then mixed in the missile guidance circuits to obtain the difference, or Doppler frequency, which reveals the target information.

With the frequency-modulation method, the wave emitted from the transmitter is varied in frequency at a fairly slow rate, so that each cycle differs from the preceding cycle by a small difference in frequency. If the frequency value increases at a constant rate and is then quickly returned to its starting value, a method is thereby provided for distinguishing one part of the emission from another.

In operation of f-m radar, two signals are introduced simultaneously into the receiver. One of these is the echo reflected from the target with a frequency value of f; and the other is the radiated signal of frequency f PLUS OR MINUS A SMALL INCREMENT, the latter being the signal which is produced at that particular moment by the transmitter. When these two signals are mixed in a detector circuit, a difference frequency is developed, the value of which is determined principally by the time required for the radar wave to travel to the target and to return. Hence, the value of the beat, or difference, frequency is an indication of the range of the target. If the transmitting and receiving antennas are highly directional, emitting and receiving energy only in certain directions, the position of the target object may also be determined from the angular position of the antennas when maximum signal strength is returned from the target.

A common application of f-m radar in missiles as well as in aircraft is the radio, or radar, altimeter, used to measure the altitude of the vehicle above the terrain below. Altim-

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eters of the f-m continuous-wave type are especially suitable for measuring low altitudes with accuracy.

A different type of radar altimeter is also employed and is based on pulse operation. The system is essentially a low-power radar which directs a broad beam of radiation downward and receives strong echoes from the ground or sea surface. As in search operation, the round-trip travel time is a measure of the distance, in this case, the altitude of the vehicle. The pulse altimeter is better adapted for high-altitude measurement than for low-level operation, and its ability to measure short ranges is considerably less than that of the f-m system.

In *Basic Electronics*, naval radar equipments were classified according to use and function into the three broad classes of search, fire control, and fighter-director systems. From this point of view, most of the radar equipment in missile systems can be considered as belonging to the fire control class. In the design of this kind of radar, emphasis is placed on good resolution and extreme accuracy in range and position measurement. To meet these requirements, high carrier frequencies are employed, and pulse equipments operate with high pulse repetition rates and narrow pulse widths. Fire control antennas usually employ parabolic reflectors, the reflecting surfaces of which are large in diameter compared with the wavelength of the emitted energy, thereby confining the radiation into narrow beams. Antenna systems contain either mechanical or electrical devices which deflect the radiated beams in systematic scanning patterns, such as LOBE-SWITCHING or CONICAL SCAN, to insure precision in locating the target. Fire control receiving circuits respond to and amplify steep-sided pulses and hence are characterized by wide bandwidths. Also, many special circuits are included for increasing the rate and accuracy of the measurements.

The operation of fire control radar differs from that of search and other systems in that a single object is TRACKED during which the entire attention of the radar is concentrated on one target. The purpose of tracking is to determine continuously its coordinates of range, azimuth, and elevation so

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as to locate it accurately in space. This operation consists principally of the two basic processes of range tracking and angle tracking.

RANGE TRACKING is usually accomplished by a group of circuits which not only measure the target range and its rate of change but also control the action of the radar receiver, allowing it to function only during a short time interval when the desired echo signal is present. The range information is derived by the use of gate pulses which occur after a varying amount of time delay following the transmission of the radar pulse. When an echo is received that occurs simultaneously with the gate pulses, the unit automatically locks on the echo and tracks it by adjusting the time of occurrence of the gate to that of the arrival of the echo. The time delay of the gate pulses then is a measure of the target range.

Sections of the receiver are disabled and no output is produced until the range unit permits the passage of the desired signal by applying an enabling voltage to the receiver circuits. By keeping the receiver inoperative except for this brief time interval, echoes from objects at ranges different from that of the principal target are excluded from the control circuits and the missile is prevented from seeking the wrong destination. Also, unwanted receptions from enemy jamming transmitters are largely prevented as well as undesirable reflections from the sea or ground.

ANGLE TRACKING consists of keeping the radar antenna pointed at the target to derive information concerning the angles of azimuth and elevation. In missile applications of fire control radar, angle tracking as well as range tracking is accomplished automatically. The radar beam is swept over the area containing the target in such a way that the returning echoes vary in amplitude with the position of the object with respect to the axis of the radar beam. The target echoes determine the receiver output, which is converted into control voltages proportional to the error in the aim of the antenna. The error voltages are then applied to servomechanisms which adjust the direction of the

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antenna to cause the system to lock on the target and follow it accurately.

The techniques of range and position measurement by radar are of fundamental importance in missile guidance. For an explanation of the principles of ranging, the reader is referred to *Basic Electronics*. To make clear the methods by which the angular error signals are derived during the process of angle tracking, it is necessary to consider the actions of the radar antenna in shaping and directing the required narrow beam and also the manner in which the energy is scanned over the target area.

Antenna Assemblies and Beam Scanning

In the operation of guidance systems based on radar tracking, the antenna assembly performs several important functions. It contains a metallic reflector and a feed device for transmitting microwave energy in narrow beams and receiving echoes only from certain directions. Since the direction of the antenna axis is the principal reference line in determining the target location, it is necessary that the antenna be stabilized so that it points in the same direction in spite of the motions of the missile in pitch, roll, or yaw. The assembly also includes some means of deflecting the beam in a regular motion to scan the target area.

Parabolic reflectors.—Many types of antenna structures have the property of concentrating radio waves into narrow pencils, or rays, but the type generally employed in tracking radars is the parabolic dish, which is similar in general appearance to the reflector used in automobile headlights. One of the important advantages of operating in the microwave region of the electromagnetic spectrum is that waves of short wavelength have properties and characteristics similar to those of light, and allow the use of reflectors such as these.

The action of the reflecting surface is the result of its shape and the fact that the rays striking and reflecting from the metallic surface make equal angles with the surface at the point of reflection. This action is illustrated in figure 4–3.

In (A) of figure 4–3, a ray arriving from V strikes the

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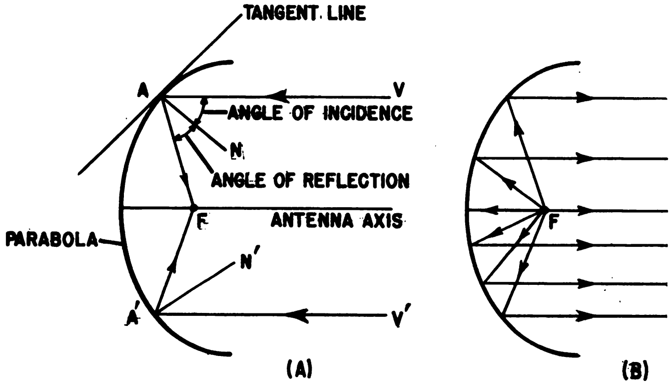

Figure 4–3.—Reflection of microwaves by parabolic surface.

reflecting surface at point A and is reflected to point F, called the *focal point* of the parabola. The line AN is drawn normal to the surface at point A, or perpendicular to the tangent line. Then during reflection the angle VAN, the angle of incidence, is equal to angle NAF, the angle of reflection, so that the reflected beam passes through the focal point. The geometry of the parabola is such that all rays along parallel paths reaching the surface, as the V', are reflected in the same manner and pass through the focal point.

The incoming rays are concentrated and brought to a point only when they enter the dish in perfectly parallel lines; and the transmission of parallel rays, as shown in (B) of figure 4–3, occurs only when the waves originate from a point source placed exactly at the focal point. In radar systems, these conditions are only approximated. The sources of electromagnetic waves are not point sources, and the beams produced are considerably wider than those indicated in the figure. And while the radiation pattern of a reflector antenna consists principally of a major lobe representing a high concentration of energy, often minor lobes are also present, indicating smaller amounts of radiation in undesired directions.

In order to obtain a narrow beam in the principal direction and to minimize the minor lobes, either the reflector must be made very large or else the wavelength must be very short, so

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as to approximate as nearly as possible the conditions of point-source radiation. This is one of the reasons for the frequent use of microwaves in radar, since they permit the formation of beams of sufficient narrowness by reflectors of reasonable size.

Figure 4–4 represents the radiation sent out by the antenna of a fire control radar. Although the angles are exaggerated, the figure shows that if the energy returned by a target hit by the center of the beam is taken as 100 percent, that returned by a target one-half of 1° off the center of the beam is 95 percent. The return from a target 1½° off is 80 percent, and the signal strength from objects decreases rapidly to 40 percent at 2° and is nearly zero at about 5°.

The importance of the beam angle lies in the fact that it determines the accuracy with which the radar can measure the angles of azimuth and elevation of the target. It also determines the angular resolution, the ability to distinguish two targets at equal ranges but slightly different bearings, since objects separated by less than the width of the beam return echoes as though they were a single object.

ANTENNA FEEDS.—Small directional antennas placed at or near the focal point are used to feed energy into parabolic reflectors and to collect the returning radar echoes and convey them to the receiver. The primary feed element may be either a small dipole or a specially constructed section of waveguide, terminated in such a way that the radiation is directed into the reflector. The feed system may be either REAR FEED, in which the waveguide extends through the reflector

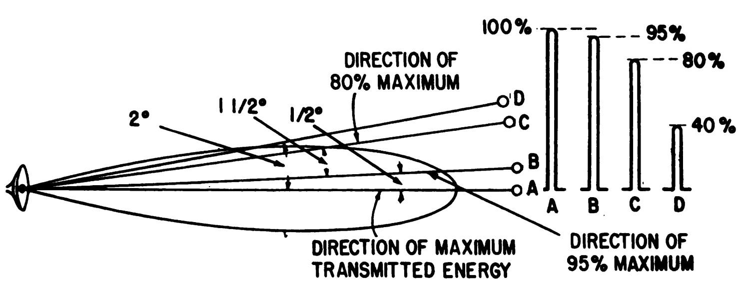

Figure 4–4.—Antenna beam.

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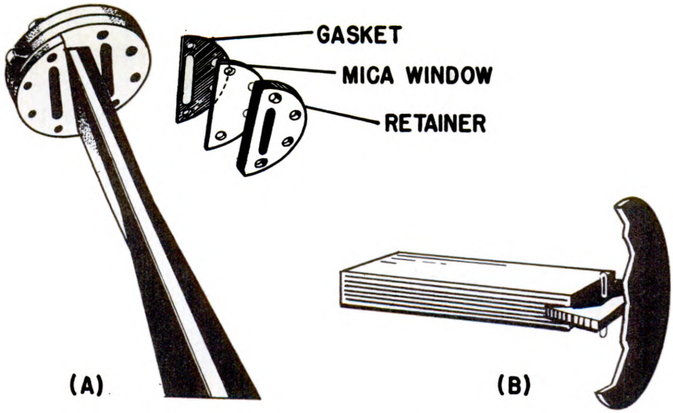

Figure 4–5.—Antenna feeds. (A) Cutler feed; (B) dipole.

from the rear, or FRONT FEED, in which the waveguide approaches the reflector from the front and releases energy directly into it. Two frequently used types of rear feed elements are shown in figure 4–5. In (A), a dual aperture horn, called a CUTLER FEED, is illustrated; and in (B), a dipole termination on a waveguide is shown.

The Cutler feed operates by radiating the energy back toward the parabolic surface through the two openings situated in the termination of the waveguide. In the dipole assembly shown in the figure, the tapered section serves as an impedance-matching device. It also improves the radiation pattern by decoupling the outer wall of the waveguide from the dipole element. Front feed systems usually employ horn radiators, composed of lengths of waveguide opening in flares through which the electromagnetic energy is released toward the reflecting dish.

ANTENNA ASSEMBLY.—An antenna assembly similar to those used in missile tracking radars is shown in figure 4–6. The drawing represents no particular unit but shows the general features of the antennas employed in missiles which carry a complete radar system.

At the center of the assembly is placed the parabolic reflector and a Cutler-type rear feed horn. Most of the additional components shown are needed for controlling the initial

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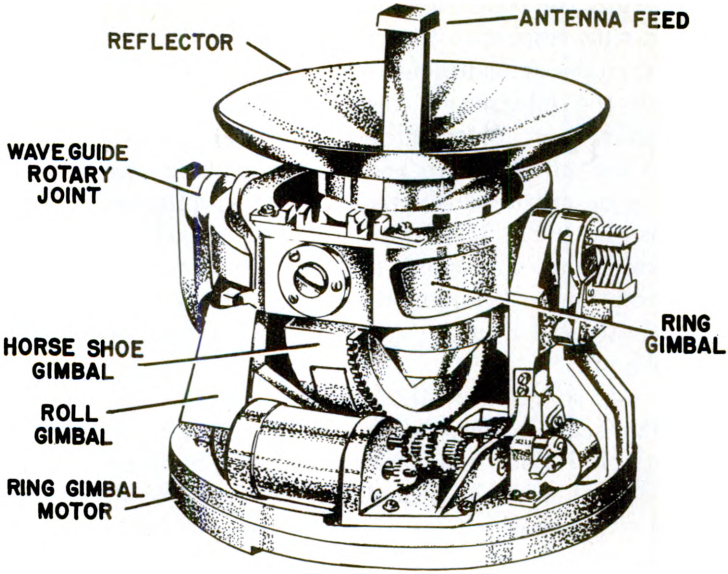

Figure 4–6.—Guidance radar antenna assembly.

antenna aim and for stabilizing its position. Stabilization is required in some cases so that the antenna axis lies along a fixed line in space, serving as a reference for measuring the bearing of the target in the establishment of an intercept, or collision course.

The reflector and associated equipment are suspended on three gimbals, or supporting frames, equipped with bearings which allow the antenna freedom to move in three dimensions. The reflector body is the basic stabilizing device since it is driven by an internally mounted electric motor and rotates at a high rate of speed. Hence it functions as a free gyroscope. Supported by the gimbals and turning at a typical speed of about 10,000 revolutions per minute, the body of the reflector maintains its axis of spin fixed, and points along the same line despite the missile motions of pitch, roll, or yaw.

Position pickoffs, or electrical devices which provide voltages dependent upon the position of the antenna relative to the missile body, are located on each of the three gimbals

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and permit the continuous measurement of the antenna direction with respect to the vehicle.

Waveguides are contained within the gimbal structures and conduct the microwave energy to and from the antenna through rotary joints situated at the gimbal bearings. Within the antenna gyro body, a two-phase reference alternator is mounted which generates two voltages displaced in phase by 90°. These voltages serve as reference values with which the echo signals are compared.

In addition to beaming the energy, the antenna deflects the radiated beam in the systematic scanning motion called conical scan.

CONICAL SCAN.—The term "scan" denotes the motion of the radar beam in space while searching for a target or while determining its position. Many scanning motions are used, but the method usually employed in missile applications is conical scan, in which the radiated lobe is rotated so as to generate a cone with its apex at the antenna.

Conical scanning can be accomplished in several ways. In the assembly shown in figure 4–6, it is produced by rotation of the reflector. The dish is mounted with its center offset slightly from the center of rotation. The feed horn remains fixed (thereby maintaining the polarization unchanged); and as the dish rotates, the focal point of the parabolic surface describes a small circle about the feed point. As a result of this motion, the beam spins in space in the manner indicated in figure 4–7. Other methods of producing a conical scan are used in which the reflector remains fixed and the feed (either horn or dipole) is rotated.

As shown in the figure, during automatic tracking the beam points at an angle of a few degrees with respect to the

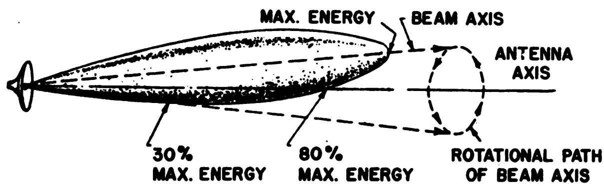

Figure 4–7.—Antenna beam with conical scan.

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antenna axis. A target located exactly on the antenna axis continuously receives a constant amount of the radiation, in this case about 80 percent of it. However, a target situated away from the axis receives radiation that varies in strength from 100 percent of maximum to less than 30 percent, depending on its displacement from the line along which the antenna is pointing. This is shown more clearly in figure 4–8, in which the return signals from a target that is 1½° off the antenna axis are contrasted with the echoes from a target on the axis.

The axis of the antenna does not change appreciably during the time required for several spins of the beam, hence the direction of the lobe after one-half revolution changes from the upper position shown in figure 4–8 to that shown in the lower position. As the beam rotates between these extreme positions, the echo signals vary gradually in strength, as shown in figure 4–9, so that the returned pulses are amplitude modulated in proportion to the displacement of the target from the antenna axis. The figure shows only eight echo signals per revolution for convenience, but in an actual case many more are present, the number for each revolution being determined by the ratio of the pulse repetition frequency to the rate of rotation of the beam.

The azimuth and elevation angles of the target with respect to the antenna axis are indicated by the phase of the variations in returned signal strength, as indicated in figure 4–9. In (A) of the figure is shown the signal resulting from an error in azimuth only; while that produced by an error in elevation alone is shown in (B). By comparing the two diagrams, it can be seen that the variation representing azimuth error is displaced in phase by 90° from a signal produced by a pure elevation error. The error signal resulting from a combination of azimuth and elevation errors is shown in (C) of the figure, in which the variation in amplitude reaches a maximum value somewhere between the moments of maximum for pure azimuth or pure elevation errors. Any other position of the target results in a similar error signal, the phase of which is determined by the amount of the azimuth and elevation errors present.

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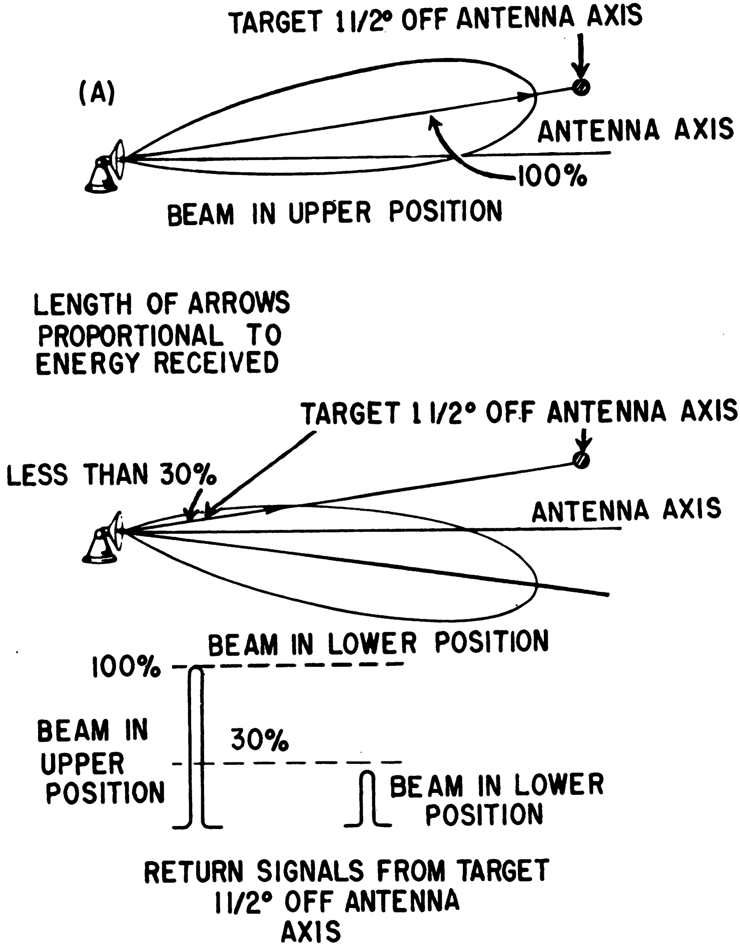

Figure 4–8.—Echo signals with conical scan.

In order to convert the signals returned from the scanning process into usable control voltages for tracking the target, it is necessary to compare the modulation on the pulses with the output of the two-phase reference generator which is synchronized with the rotation of the antenna. The two reference voltages are displaced in phase by 90° so that one is in phase with a pure azimuth error signal and the other with a pure elevation error.

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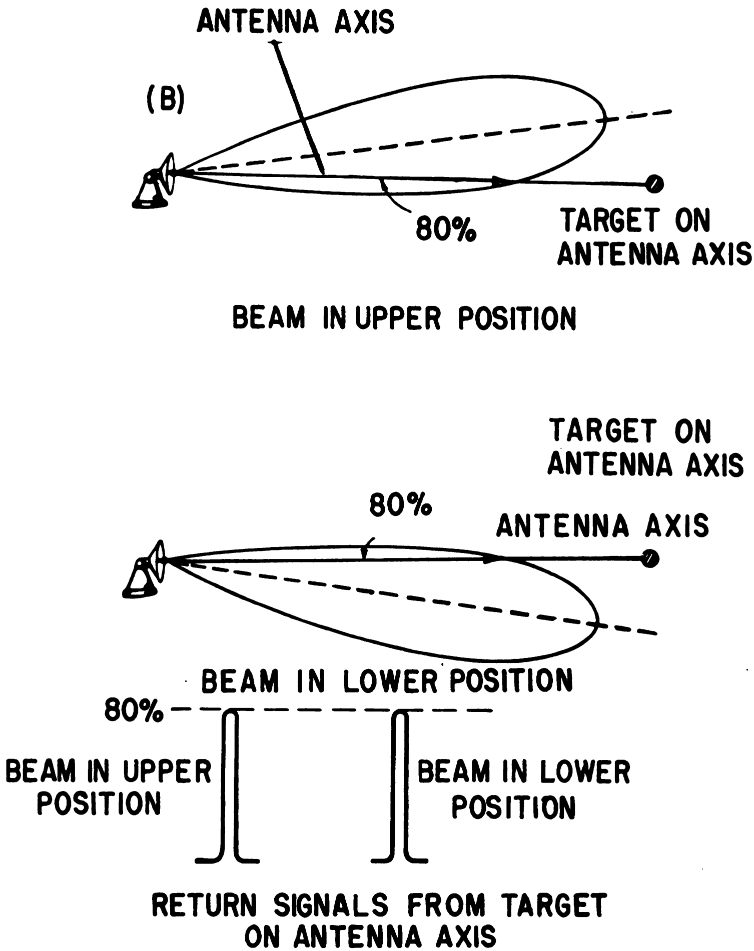

Figure 4–8.—Echo signals with conical scan—Continued

When the axis of the antenna points directly at the target, the echo pulses are all of equal amplitude, as shown in (B) of figure 4–8. In automatic tracking, the error control voltages are applied to servomechanisms which position the antenna so as to zero the error signals and maintain the antenna aim fixed on the target.

Lobe switching.—In the operation of some missile radar

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systems, the azimuth angles of stationary targets are determined by the scanning process called lobe switching. A lobing antenna produces two beams, one at a time, switching rapidly from one to the other. The directions of the two differ by a small angle equal to about one beamwidth, and signals are returned as each beam strikes the target. When the two echoes are compared, the strength of one with respect to the other depends upon the position of the target in relation to the antenna direction, as shown in figure 4–10.

The returning signals are equal in strength only when the reflecting object lies on the line bisecting the angle of intersection of the two lobes. If the target is situated on either side of this line, the echoes differ in amplitude in such a way as to indicate whether it is to the left or to the right of the antenna direction. The two signals are compared visually in some fire control radars, but in missile systems they are

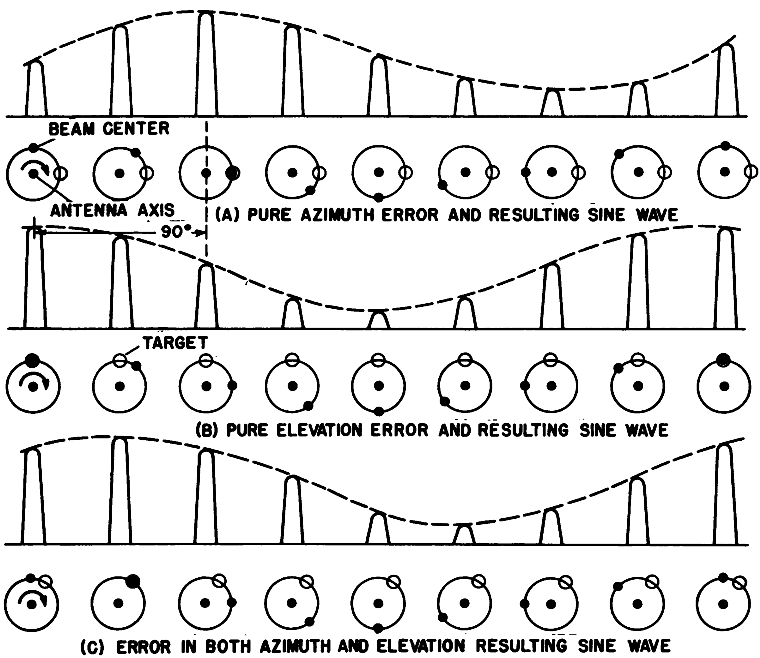

Figure 4–9.—Signals produced by azimuth and elevation errors.

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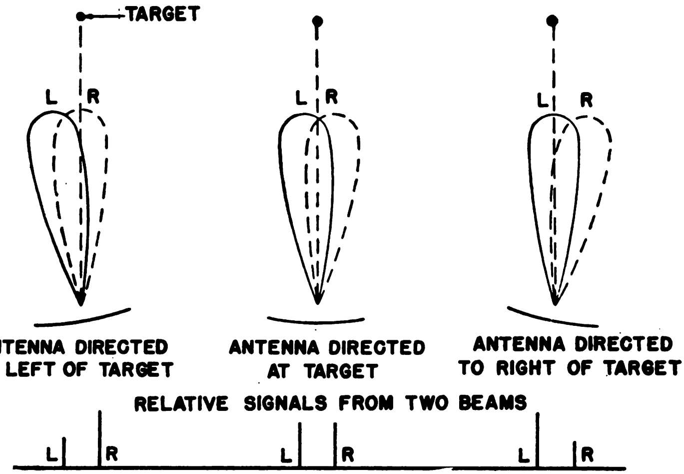

Figure 4–10.—Lobe switching.

compared electrically and fed directly into circuits that adjust the antenna direction for equal amplitudes of the received signals.

Typical Missile Radar System

The basic components of a radar system similar to those used in missiles employing active homing guidance are indicated by the block diagram in figure 4–11. In this kind of guidance, the missile carries a complete and independent radar set which both transmits energy to irradiate the target and receives echoes from it. The diagram represents no specific radar set, but is intended to exhibit the fundamental operation of this specialized type of equipment.

In order to conserve space, the components in this type of system are arranged in very compact assemblies and subassemblies, and most of the electronic tubes and related parts are of subminiature construction. Usually, the larger elements are those which are involved in the generation, control, and transmission of superhigh-frequencies; and these are grouped together to comprise the MICROWAVE ASSEMBLY.

The individual members of the microwave assembly are

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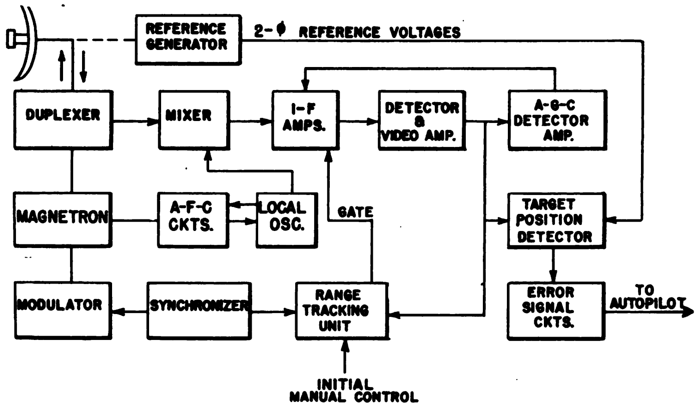

Figure 4–11.—Block diagram of typical radar for active homing.

the magnetron, which originates the microwave energy; the duplexer, containing the TR and ATR tubes which act as a switch for connecting the antenna first to the magnetron and then to the receiver input; one or more mixers; the klystron oscillator; the antenna assembly; and various sections of waveguide.

Closely associated with the action and functioning of the microwave components is the SYNCHRONIZER, which supplies the timing pulses for initiating the numerous processes of the entire system, and the MODULATOR, which supplies high voltage to the magnetron, allowing it to operate for very short intervals of time to produce the pulses of microwave energy.

The superhigh-frequency waves from the magnetron are coupled to the antenna through the DUPLEXER. This unit has the same function described in *Basic Electronics*, but in missile applications it is usually of special construction and is small in size, being similar in appearance to the unit illustrated in figure 4–12.

The antenna, usually similar to the unit shown in figure 4–6, is equipped as a rule with waveguide feed, and is mounted on gimbals. The gimbals are formed from sections of waveguide and serve both to support the antenna and to

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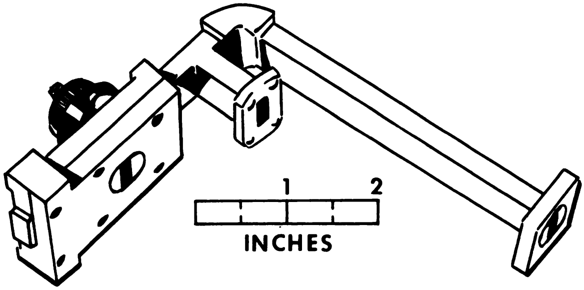

Figure 4–12.—Duplexer.

conduct electromagnetic energy to it for transmission, or from it to the duplexer and then to the mixer during reception. The antenna is usually covered by a specially designed surface called a RADOME. Since target tracking antennas are located in the nose of the missile, the radome is aerodynamically designed with good physical strength, and yet does not interfere seriously with the propagation of the radar waves. Most of the missile radomes are constructed of nonmetallic materials so that they do not distort or reflect the radar beam and must be handled with care.

In the MIXER, the output of the local oscillator is combined with the echo signals to produce the intermediate-frequency (i-f) voltages, the values of which are in the order of 60 megacycles. The physical construction of a miniature waveguide-type mixer is shown in figure 4–13.

The receiving section not only detects the returned signals,

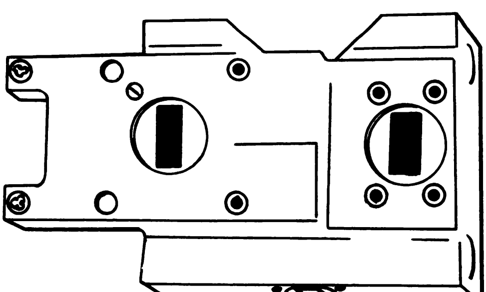

Figure 4–13.—Mixer construction.

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but also extracts from them the information necessary for guiding the missile. Since conical scan is usually employed, the information is in the form of amplitude and phase variations of the received echo pulses. And in addition to the usual receiver circuits, such as i-f amplifiers, a detector, video amplifiers, and automatic-gain-control (AGC) circuits, the system illustrated in figure 4–11 also contains a TARGET POSITION detector and a section labelled error signal circuits.

After conversion, amplification, and detection of the received pulses, the output of the video amplifier is applied to the position error detector which measures its amplitude and phase by comparison with the output of the two-phase reference generator. The resulting signals are applied to the error signal amplifiers for application to the autopilot. An important part of the receiver is the AUTOMATIC-FREQUENCY-CONTROL (AFC) system, the function of which is to continually adjust the frequency of the local oscillator so that it differs from the magnetron frequency by the exact value of the intermediate frequency. The RANGE TRACKING UNIT receives pulse information from the video circuits and from the synchronizer, and produces the gate pulses which gate the intermediate-frequency circuits to provide range discrimination.

Components which illustrate the construction of missile receiver circuits are shown in figures 4–14, 4–15, and 4–16.

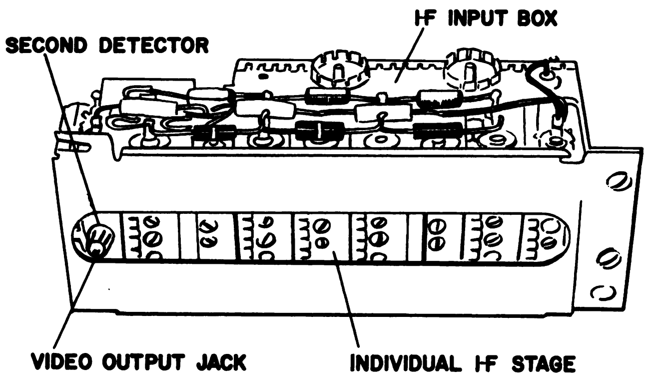

Figure 4–14.—Receiver i-f assembly.

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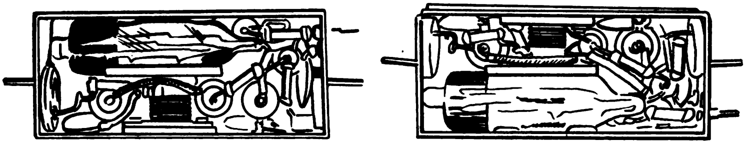

Figure 4–15.—Individual i-f stages.

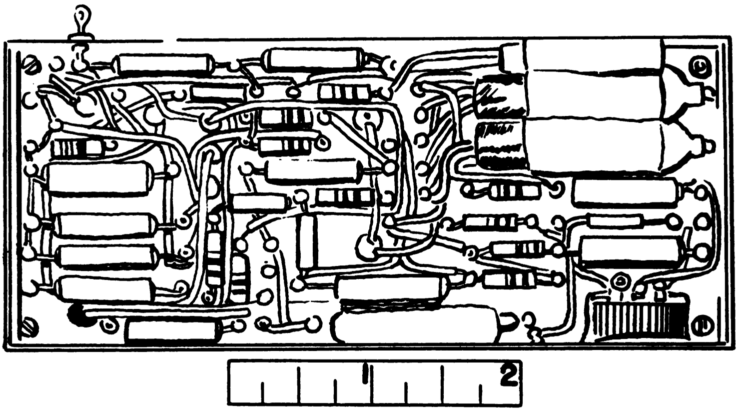

Figure 4–16.—Parts arrangement in typical assembly.

In figure 4–14 is shown a typical i-f strip. The complete assembly plugs into the mixer unit and contains nine stages of amplification and the second detector.

The complete i-f amplifier unit is built up of smaller units, each containing one i-f stage. This type of construction provides interstage shielding and has the mechanical strength and rigidity required for missile operation. Two of the individual stages are shown in figure 4–15. The tubes used in these circuits, as well as elsewhere in the receiver section, are of the subminiature type of construction.

A further example of the compactness of the electronic parts is shown in figure 4–16.

INFRARED APPLICATIONS IN MISSILE HOMING

Many military targets, such as ships, factories, aircraft, and guided missiles, are warmer than their surroundings and

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may be detected by missile guidance equipment because of the large amount of heat they emit. Homing-guidance equipment, usually located in the nose of the missile, gathers this radiation from distant objects which lie in its field of view, and transforms it by optical and electrical processes into voltage signals. These signals are then used by the autopilot in the same manner as signals from radar guidance equipment to control the flight path of the missile.

Before discussing the operation of this type of guidance equipment, it is necessary to consider the nature of heat and how it is transferred from one object to another.

Properties of Heat Radiation

Heat is produced in any material whose temperature is above absolute zero (−273° C.). It is the result of the motion of the molecules, and is a form of kinetic energy which can be transferred by only three processes—conduction, convection, and radiation.

In the process of CONDUCTION, the energy is transferred from molecule to molecule by actual contact. Metals, in general, are good conductors of heat, and because the molecules are farther apart in gases than in solids, the gases are much poorer conductors.

CONVECTION is the process in which heat is transferred by moving a heated substance. For example, an electronic tube gets hotter and hotter until the air surrounding it begins to move. The motion of the hot air is upward. This upward motion of the heated air carries the heat away from the hot tube by convection.

Our main source of heat, the sun, supplies us with energy through empty space. This is not accomplished by conduction or convection, because these two processes take place only through a medium, such as a gas or a solid. This heat is transferred by a third process known as RADIATION. It is emitted from the surface of all bodies, as well as the sun, in the form of electromagnetic waves, and is identical in nature with radio waves, light waves, and X-rays except for a difference in wavelength.

These electromagnetic waves which produce heat in any

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object that absorbs them are called INFRARED waves because their frequencies are just below those of the color red in the spectrum, as shown in figure 4–17. As these frequencies are in the millions of megacycles, it is convenient to specify them in terms of wavelength. The unit of wavelength most commonly used for these frequencies is the MICRON, which is 10^{-6} meters. In microns, the infrared band extends from about 300 microns to 0.76 microns.

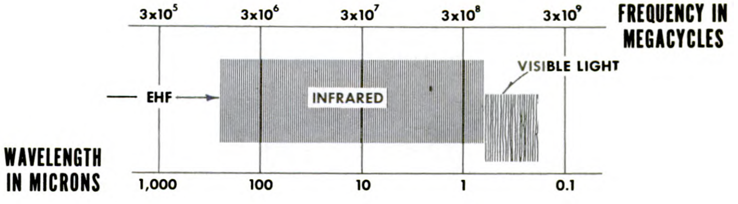

Figure 4–17.—Infrared portion of electromagnetic spectrum.

Infrared waves are emitted from a substance by the same process that radio waves are emitted from an antenna. The motion of the electrons of the moving molecules produces electromagnetic fields, some of which escape from the surface and are radiated into space at the speed of light.

The frequency of the radiation from a body is determined by the speed of motion of the surface molecules. Their motion is random and of many speeds, thus, the radiation consists of many frequencies. The frequency of maximum radiation, however, depends on the temperature of the body. This is shown in figure 4–18, which is a plot of the radiation from four objects at different temperatures. Note that very high temperatures (such as those developed in a rocket motor) produce both visible and infrared radiation, and that cooler objects (such as a flatiron) produce only infrared.

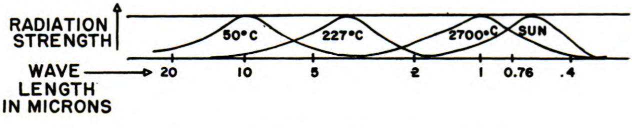

Figure 4–18.—Radiation at different temperatures.

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Since infrared waves are of the same nature as radar and light waves, they have similar characteristics. The differences in the behavior of infrared from that of visible light or radar waves are largely because of the differences in frequency. Infrared is reflected and refracted in a manner similar to light, however, it suffers less absorption when passing through light fog or haze than does visible light; but rain, snow, and water attenuate both to approximately the same extent. Therefore, like radar waves, infrared waves require a relatively clear line of sight for reception.

When infrared is absorbed by an object, the electromagnetic energy increases the speed of motion of the molecules which causes the temperature of the object to increase. Thus, infrared can be detected by its heating effect.

Infrared Detectors

Exhaust gases from internal-combustion propulsion systems radiate, in general, low-frequency infrared which can be detected by heat-sensitive devices. Jet propulsion systems, however, require very high combustion temperatures for operation, and in addition to infrared, they emit frequencies in the visible portion of the spectrum which can be detected by photosensitive devices.

Most of the detecting devices used in infrared homing equipment are resistive elements which have a large temperature coefficient of resistance, that is, the change in the specific resistance per degree centigrade, as explained in chapter 6 of *Basic Electricity*, NavPers 10086. The most common of these detectors are BOLOMETERS and PHOTOCONDUCTIVE CELLS.

There are two main classes of bolometers—BARRETTERS and THERMISTORS. A barretter, often called a bolometer, consists of a short length of very fine wire usually platinum, which has a positive temperature coefficient of resistance. (A resistance has a positive temperature coefficient if its value increases with temperature, and a negative coefficient if its value decreases with an increase in its temperature.) The thermistor is a type of variable resistor made of semiconducting material, such as oxides of manganese, nickel,

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cobalt, selenium, and copper. It has a negative temperature coefficient of resistance. Thermistors are made in the form of beads, disks, rods, and flakes, some of which are shown in figure 4–19.

The heat-sensitive materials of thermistors are mixed in various proportions to provide the specific characteristics of

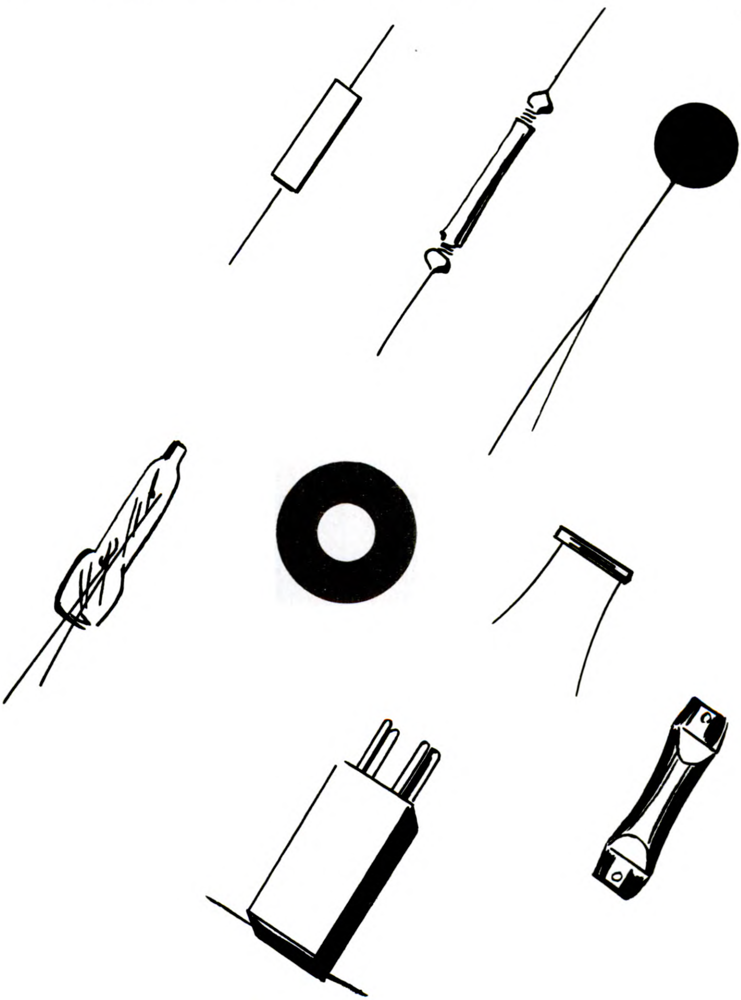

Figure 4–19.—Various thermistors.

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resistance versus temperature necessary for target detection. Figure 4–20 shows the change in resistance which can be produced in a typical thermistor material and in a barretter. This comparison shows that the thermistor has the larger temperature coefficient of resistance, and therefore is the more sensitive. Thermistors have been developed which are sensitive to temperature changes of ½° F.

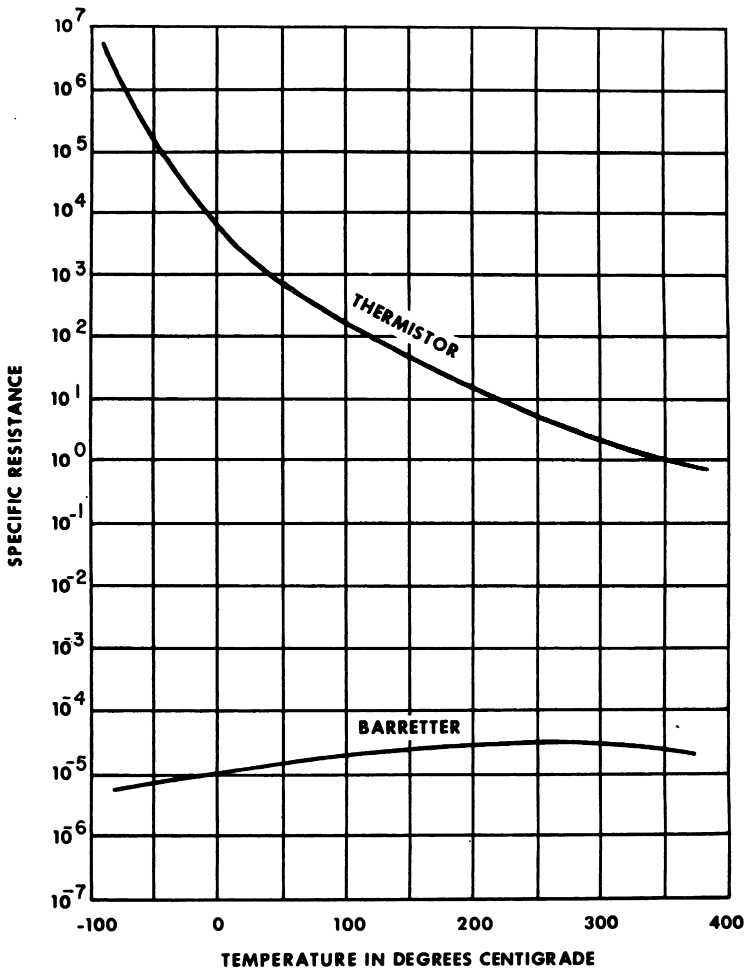

Figure 4–20.—Resistance-temperature comparison of thermistor and barretter.

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Photoelectric detectors operate by producing an electrical signal when stimulated by high-frequency infrared or visible radiation. They are divided into three kinds—photoemissive, photovoltaic, and photoconductive. The PHOTOEMISSIVE type includes vacuum- and gas-filled phototubes and photomultipliers. In this type, the main effect of the radiation is the production of an electric current in a device having an input impedance of thousands of megohms. They are in common use in sound moving-picture systems, but are not applicable to missile guidance systems. The PHOTOVOLTAIC CELL is used in the familiar photographic light meter; and although it produces small voltages in a low-resistance device, it is generally too sluggish for target-tracking purposes.

The PHOTOCONDUCTIVE CELL utilizes an element whose resistance varies with the incident radiation and operates in the same manner as a thermistor. Some of the materials used in these cells are thallous-sulfide, lead-sulfide, lead-selenide, and lead-telluride. The thallous-sulfide cell has the highest speed of response to infrared, and is therefore more adaptable for high-speed target tracking required in missile homing systems.

Target Detection

These detectors, whether bolometers or photoconductive cells, are used as integral parts of the homing head. They are placed either at the focal point of a parabolic mirror or else are employed in conjunction with lenses which provide maximum concentration of the infrared signals at the sensitive surface. As the waves are received from the target, the concentrated radiation is focused on the detector, causing it to change its resistance. A comparatively small d-c voltage is applied to the detector element; and the variations in the resistance caused by the radiation result in corresponding voltage variations.

One method of obtaining directional information is by the use of a rotating mirror whose axis is offset from the axis of rotation so that the focal point describes a small circle. In this arrangement, the detector often consists of four elements

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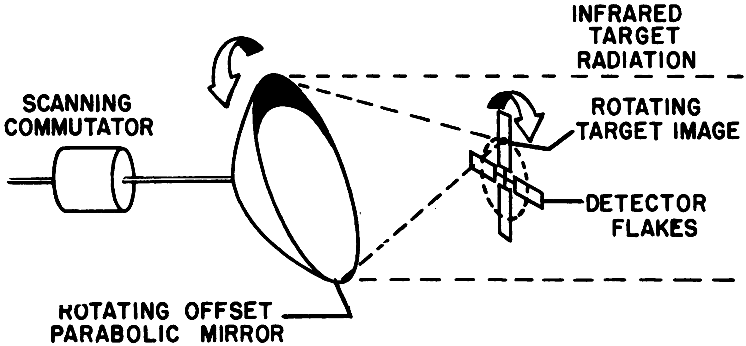

Figure 4–21.—Infrared detection.

arranged in a cruciform pattern. It is placed so that the focused radiation sweeps across each of the elements in succession, as shown in figure 4–21.

In addition to the mirror and detector, two commutators are included in the homing head each of which contains a pair of conducting segments separated by insulating spaces. One commutator connects one pair of bolometer flakes to the left-right control circuits, while the other connects the remaining pair to the up-down circuits. Each commutator has a rotating arm which is driven by the mirror shaft.

When the target is dead ahead, the rotating target image formed by the mirror describes a circle centered with respect to the bolometer arms. As a result, the bolometer arms divide the circle into four 90-degree sectors, as shown in figure 4–22 (A). In this condition, each time the image intersects one of the bolometer arms, the signals developed cannot pass to the control circuits, because at this instant the commutator arms are on one of the insulating segments. Thus no error signals are applied to the control circuits.

In (B) of the figure, the condition is shown with an off-center target. The circle of the rotating target image is now offset from the center of the bolometer. In this condition, the bolometer arms divide the circle into unequal sectors; and as a result, the image intersects the flakes when the commutator arms are on the conducting segments. The signals will now pass through both commutators to the missile con-

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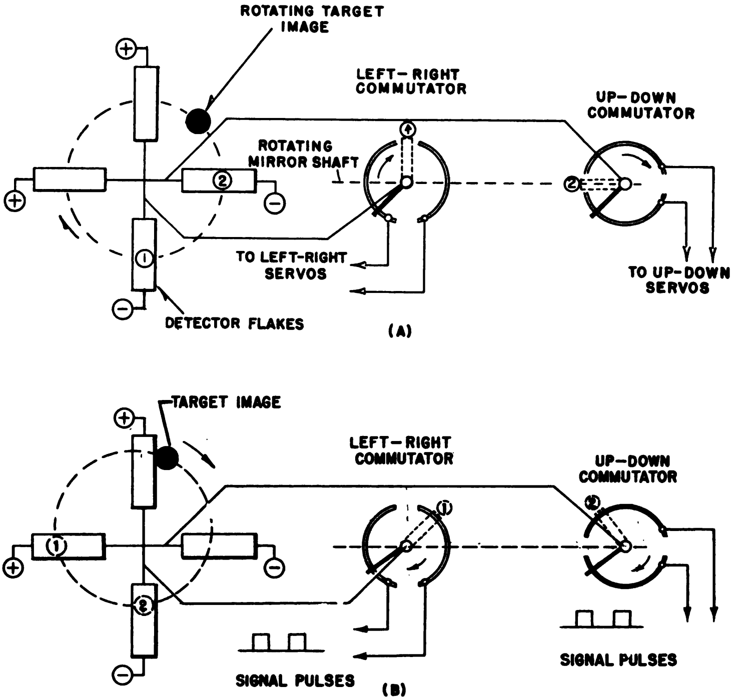

Figure 4-22.—(A) Centered target; (B) target off center.

trol circuits which cause the proper corrections to be made in the flight path.

This chapter has introduced some of the equipments and techniques employed in the processes of target tracking. The following chapters are concerned with the applications of these in the various guidance systems used in air-launched missiles.

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QUIZ

1. The guidance systems most suitable for air-launched missiles are
   a. beam-rider, homing, and command
   b. homing, command, and self contained
   c. beam-rider, command, and baseline
   d. beam-rider, baseline, and self contained

2. With command guidance
   a. tracking of the missile is never required
   b. the missile and target are tracked independently
   c. flight path orders are derived in the missile
   d. a computer is never required

3. In pulse radar equipments, the requirements of good resolution and extreme accuracy in range and position measurement are met by using
   a. high pulse-repetition rates and wide pulse widths
   b. low pulse-repetition rates and high carrier frequencies
   c. high carrier frequencies and wide pulse widths
   d. high pulse-repetition rates and narrow pulse widths

4. Narrow beams are usually generated in fire control antenna systems by using
   a. conical scan
   b. lobe switching
   c. parabolic reflectors
   d. half wave directors

5. Tracking with a fire control radar consists principally of the two basic processes of
   a. range tracking and speed tracking
   b. range tracking and angle tracking
   c. azimuth tracking and speed tracking
   d. azimuth tracking and elevation tracking

6. Keeping the radar antenna pointing at the target in order to derive information concerning target azimuth and elevation is called
   a. angle tracking
   b. target search
   c. detection phase
   d. space stabilization

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7. Radio waves striking a parabolic reflector are concentrated and brought to a point if

   a. they strike the reflector perpendicular to the tangent line
   b. they originate at the focal point
   c. they enter the dish in perfectly parallel lines
   d. the antenna has only one major lobe

8. The antenna system of a radar, employing lobe switching for deriving azimuth information, would usually produce

   a. four beams one at a time
   b. two beams at the same time
   c. four beams at the same time
   d. two beams one at a time

9. In the typical active homing radar, the unit which supplies the timing pulses is the

   a. modulator
   b. synchronizer
   c. local oscillator
   d. duplexer

10. In the process of CONDUCTION, energy is transferred

   a. from molecule to molecule by actual contact
   b. by moving a heated substance
   c. by reflection from a heated object
   d. by radiation from heated molecules

11. The emission of heat from the surface of bodies in the form of electromagnetic waves is a process known as

   a. conduction
   b. convection
   c. reflection
   d. radiation

12. The Micron is employed to measure

   a. frequency
   b. wavelength
   c. temperature
   d. velocity

13. The frequency of radiation from a body depends upon the

   a. velocity of the body
   b. size of the body
   c. speed of the surface molecules
   d. reflectivity of the surface

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14. When infrared is absorbed by an object, the electromagnetic energy__________the speed of motion of the molecules which causes the temperature of the object to__________.

   a. decreases; decrease
   b. increases; decrease
   c. decreases; increase
   d. increases; increase

15. The barretter consists of__________and has a__________temperature coefficient.

   a. a short piece of platinum wire; negative
   b. beads, disks, rods, and flakes; negative
   c. a short piece of platinum wire; positive
   d. beads, disks, rods, and flakes; positive

16. The four basic processes in missile guidance and control are

   a. tracking, computing, detecting, and steering
   b. detecting, directing, computing, and steering
   c. tracking, computing, directing, and steering
   d. launching, tracking, computing, and directing

17. The process of using tracking data to formulate necessary directions for control is known as

   a. steering
   b. detection
   c. directing
   d. computing

18. In the__________operation, the target is kept under constant observation, and its position relative to the missile is continuously determined.

   a. tracking
   b. computing
   c. detection
   d. search

19. In homing systems, the emission from the target may originate

   a. at the target
   b. in the missile
   c. in the launching aircraft
   d. at any of the above

20. The operation of a c-w radar system depends on

   a. Doppler effect
   b. high PRF
   c. narrow pulse width
   d. lobe switching

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CHAPTER 5

BEAM-RIDER AND COMMAND GUIDANCE SYSTEMS

BEAM-RIDER GUIDANCE

The beam-rider system now employed in many types of air-launched and surface-launched guided missiles bears a close resemblance to a method for controlling rockets first proposed as long ago as 1925. At that time it was suggested that a rocket could be made to climb the beam of a searchlight by the use of a simple control system containing four selenium cells. The light-sensitive cells were to be attached to the tail assembly of the rocket in a symmetrical arrangement; and after launching, the rays of the guiding searchlight would fall equally on the four cells as long as the projectile remained in the center of the illuminated path.

If the rocket should stray from the desired track, the four cells would then intercept different amounts of light. And since the electrical resistance of a selenium cell is a function of the intensity of the light falling upon its sensitive surface, the unequal responses of the four units could be converted into corresponding electrical signals. The signals were to be applied through amplifiers to a transmission system which would in turn act upon the rudders so as to steer the rocket back toward the center of the beam.

While this early scheme was never developed in exactly the form first proposed, it is nevertheless interesting and noteworthy since the modern beam-rider guided missile works on exactly the same general principle, although with numerous refinements and variations. Instead of a light beam, the missile system employs the beam of a fire control radar for guidance; and the modern techniques of automatic tracking

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in range and angular position increase the accuracy of the guidance process. Instead of selenium cells, the missile carries microwave antennas which are used as sensing elements. With these it receives special guidance signals emitted by the parent equipment; and by means of electronic circuits, gyroscopes, and servomechanisms included in its control system, it locates the center of the radar beam and follows it to the target.

The basic components and their general functions in a typical system are described in the following discussion; but before proceeding, it is desirable to consider first the tactical use of the weapon of which they are a part.

Tactical Operation of the Missile

The operation of a beam-rider missile as a part of a naval weapons system is illustrated in figure 5–1. The engagement shown consists of the interception of an enemy aircraft followed by an attack with the radar-directed missile. ~~The~~ An enemy plane is first detected by a search radar ~~located on~~ board ~~a~~ carrier; and the pilot of a fighter aircraft aloft is

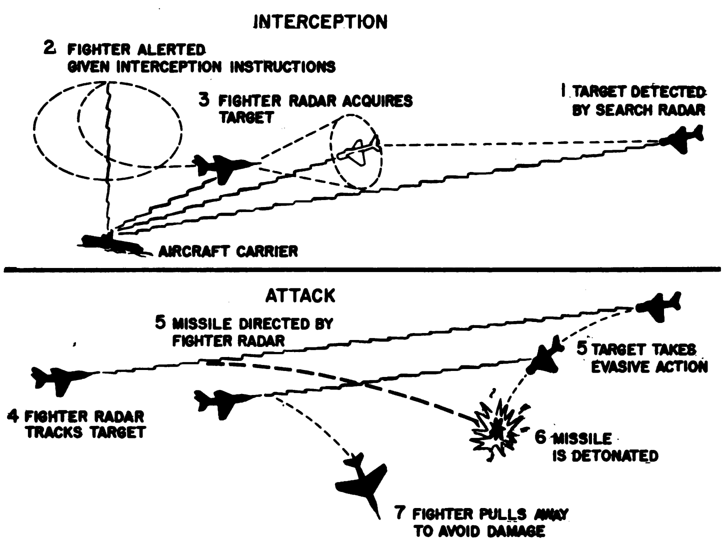

Figure 5–1.—Operation of the beam-rider system.

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alerted by radio and given instructions for intercepting the intended victim.

The fighter plane carries from one to four missiles and also the primary guidance equipment of the total missile system, a fire control radar which tracks the target during the attack and provides the radar course along which the missile will fly.

During the interception phase of the engagement, the missile is supplied with electrical power through cables attached to the umbilical connection. This power energizes the vacuum-tube filaments, supplies the keep-alive voltages in the T–R switching tubes, and runs the gyroscopes, which are included in the missile control section.

The attack phase begins when the fighter radar locks on the target and begins the tracking operation, pinpointing the target both in range and in angular position. The range units of the fire control radar constantly measure the instantaneous distance to the target and the closing speed. The conically scanning radar beam tracks the target in elevation and azimuth. After tracking has continued for a short period of time, a computer in the fire control set indicates to the pilot that the correct range for launching has been reached, and the final treatment begins.

When the firing button is pressed, the following events take place: The missile gyroscopes are uncaged and power removed, permitting them to coast by momentum during the brief flight of the weapon; the external supply voltage is cut off and the internal power supply in the missile is connected to the electronic circuits; the rocket motor is fired; the umbilical connection is broken; and the missile is on its way.

After launching, the pilot must fly a course which permits the tracking radar to keep the beam locked on the target. Before entering the beam, the missile is steered by signals derived from its gyroscopes. After reaching the beam, its guidance circuits receive radar position signals which are converted into wing-command voltages. These act upon the wing-control section so that the missile is steered along the beam to its destination. The attack course is maintained

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by the launching aircraft until the weapon approaches within lethal range of the target, where the warhead is exploded by the action of the proximity fuze.

Phases and Functions of Guidance

In the combat action illustrated in figure 5–1, the flight of the missile can be divided into two well-defined periods. These are called the PROPULSION, or THRUST, and the GLIDE, or GUIDANCE, phases. The first is the time interval during which the rocket motor is burning, thereby applying thrust, and accelerating the weapon to operating speed. At the time of total motor burnout, usually about two or three seconds after launching, the missile enters the guidance phase and travels by momentum during the remainder of the flight.

The control requirements are considerably different in the two phases; and to guide the weapon effectively in both, the control system components in the missile must employ two distinct methods of operation. The system is usually designed to operate first, as an AUTOMATIC-PILOT system; second, as a BEAM-GUIDANCE system, both of which operate a common servo system.

The automatic-pilot function is in effect during the propulsion phase. Just after leaving the launching rack, the missile is not in the effective region of the radar beam; and the autopilot then conducts it along a predetermined course which intersects the line of the beam by the time acceleration ends. Some type of timing device, for example a stepping relay, operates at the end of the maximum motor burning time and transfers control to the guidance function. The missile then receives and decodes the radar guidance signals, following the beam until it reaches the target.

It is the function of the servo system to convert the electrical command signals supplied by the other two systems into wing deflections. This is accomplished by the action of vacuum-tube circuits and electromagnetic devices which supply signals to the wing-actuating servomechanisms. The latter are usually hydraulic units, although pneumatic

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systems are employed in some missiles for deflecting the control surfaces.

In each of the two control methods, the missile is controlled in pitch, yaw, and roll. The components which supply the wing commands are described in the following pages; and since the autopilot function occurs first in the sequence, the units which are active in this portion of the flight are considered before those which operate in the beam-guidance phase.

The Thrust Phase

While the propellant is burning in the thrust phase, the beam-rider missile flies as a ballistic rocket, except that the automatic pilot, operating through the servo system corrects for any deviation from the desired course. Control of the missile in the autopilot function is based on the output signals of sensing instruments such as gyroscopes and accelerometers, which detect changes in heading and attitude and the rates at which these changes take place. When undesirable motions of the weapon occur, these instruments then supply corresponding error signals to a summing amplifier, which combines the various signals and converts them into input voltages for the wing-actuating units. These deflect the wings, or control surfaces, so that the missile is steered along the required course.

A discussion of the details of the gyroscopes and other sensing instruments and of the units of the servo system must be reserved for a later chapter. It is necessary here to consider only the kinds of units involved and their essential functions in the autopilot operation. In general, these units enable the autopilot to supply two kinds of control—pitch-yaw correction and roll control. The former governs the heading of the missile and corrects the flight path with respect to the pitch and yaw axes. The latter control governs the rotation of the airframe about the longitudinal axis.

PITCH-YAW CONTROL.—The block diagram in figure 5–2 gives an example of the units contained in an autopilot pitch-yaw control system. In this arrangement, the pitch

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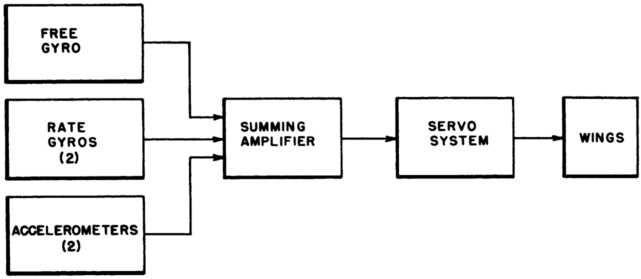

Figure 5–2.—Autopilot pitch-yaw units.

and yaw error signals originate in the outputs of three groups of instruments: A free gyroscope, two rate gyroscopes, and two accelerometers. These measure changes in heading, rates of change, and acceleration at right angles to missile flight path, respectively. The output voltage of each instrument is applied to a summing amplifier, which combines the separate voltages into the pitch and yaw error signals for the servo system.

The free gyro provides a fixed reference line in space directed along the axle of the rotating gyro wheel, the basic part of the instrument. The wheel is mounted in gimbal rings which permit freedom of movement for the rotor in three dimensions. And as a result of gyroscopic forces, the spin axis of the rotating wheel remains unchanged in direction, even when the missile pitches and yaws.

At launching, the free gyro is uncaged in a position so that the axis of the rotor lies along a line parallel with the desired missile heading. This direction, which is also parallel with the longitudinal axis of the missile at launching, is maintained by the gyro during flight, thereby providing the required reference line against which changes in missile heading can be measured.

When the vehicle deviates from the preset heading, two potentiometers (one for pitch and one for yaw) attached to the free gyro gimbal rings then develop voltages proportional to the amplitude of the change in heading. These voltages are combined with additional signals from the rate gyros, which detect the rates of rotation about the lateral axes.

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Also added are the signals from the accelerometers which represent the components of acceleration at right angles to the flight path.

The signals of the free gyro, when applied to the summing circuits, result in wing commands which tend to bring the missile back to the original course. The output signals of the rate gyros and the accelerometers act in opposition to the free gyro signals and provide feedback action which opposes any missile motion in pitch or yaw. By adding the feedback signals, damping of the missile response is provided and the tendency to overshoot or oscillate about the desired course is thereby minimized.

In the ideal case, the missile flies along the preset course and the outputs of the control instruments are zero. But in practice, slight misalinements of the wings or tail fins, unbalance in the control surfaces, air turbulence, or other disturbances may cause the missile to swing from the required path. The control instruments then initiate corrective actions by supplying input voltages to the summing circuits.

The summing amplifier and servo sections of the block diagram (fig. 5–2) are common to both the autopilot and the beam-guidance functions, the principal difference in the two phases being that the input signals are derived from different sources. The summing section contains three channels, corresponding to the three types of error voltages involved, that is, pitch, yaw and roll. In the summing circuits, the error signals are combined, amplified, and limited. During autopilot operation, the free gyro and feedback voltages are combined, or summed, by applying them to resistance networks in the appropriate channels. The resultant voltages are amplified and applied to the limiters. The purpose of the limiting action is to prevent excessive deflections of the wings; and to accomplish this, the error voltages are clipped if they exceed the safe maximum value but remain unaffected by the limiters if less than this critical voltage.

The principal units of the servo system are amplifiers and wing-actuator assemblies. The servo amplifier, like the summing section, contains three channels which accept the

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pitch, yaw, and roll error signals. After amplification the voltages are applied to the wing-control servos, which convert the electrical impulses into wing motions of the proper direction and amplitude.

ROLL CONTROL.—In many air-launched missile systems, the autopilot causes the weapon to rotate during the thrust phase in a manner similar to the spin given a bullet in flight. The rolling motion increases stability by reducing the effects of undesirable lateral acceleration. Such acceleration may result from offset thrust of the rocket motor, from unbalance in the missile control surfaces, or from similar forces which cause sideward motion. If the missile body is caused to roll, the direction in which the lateral force acts is then constantly changed; and the resulting displacement is distributed throughout 360 degrees during one rotation of the airframe. As a result, the deviation in any particular direction is reduced and the correction required of the autopilot is considerably minimized. The principal effect on the flight path of adding roll to the undesirable sideward thrust is that the missile then flies on a corkscrew track, or tight spiral, about the required course.

The units of the autopilot which produce and govern the rolling motion are represented in figure 5–3. In this system, the signal applied to the servo units to cause the motion is derived from two voltages fed to the roll channel of the summing amplifier. These are the roll command, a fixed bias voltage, and the output of a rate gyroscope which pro-

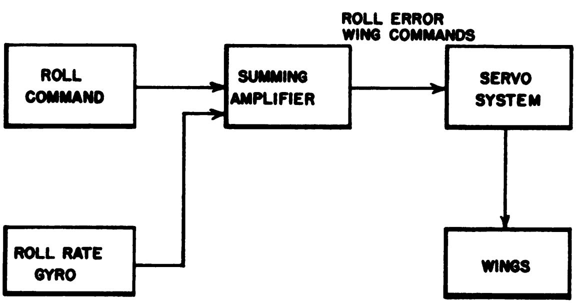

Figure 5–3.—Autopilot roll control units.

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vides a signal proportional to the rate at which the missile rotates about the longitudinal axis.

The roll command acting alone results in rotation. The roll rate signal is subtracted from it to provide feedback; and the resultant is then the roll error signal which is applied through the servo amplifiers to the wing-actuating units. The wing units respond by operating one or more pairs of wings differentially: one member of the pair is deflected in a direction opposite to that of the other member. This type of deflection, which is similar to the motion of the ailerons of an aircraft wing, supplies the required rolling action of the airframe.

The control of the missile path in pitch, yaw, and roll by the autopilot instruments and the servo system continues to the end of the thrust phase, when the operation of the timed switching device transfers the control system to the guidance phase. The gyros and accelerometers which supplied the guidance information during acceleration of the weapon are then disconnected from the input terminals of the summing amplifier; and a new set of components and circuits are attached. These develop the wing commands for the servo system by receiving and processing the emissions of the companion radar.

The Guidance Phase

After the autopilot has conducted the missile into the narrow pencil of rays transmitted by the launching aircraft, the weapon becomes a true beam-rider; and its success in finding the target then depends upon the response of its guidance circuits to the radar signals. Before considering the missile circuits, however, it is first necessary to understand clearly the actions of the parent radar in providing two essential factors of the guidance process. These are: First, the required course to the target; and second, a reference system which enables the missile circuits to measure the weapon's position in space with respect to this course.

The path along which the missile must fly is defined by the tracking operation of the aircraft radar. Prior to launching and throughout the thrust phase, the fire control antenna

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is directed automatically by the tracking equipment so that the conically scanning radar beam follows the target and retains it at the center of its cone of scan. The axis of the scanning cone, an imaginary line in space connecting the tracking antenna and the instantaneous position of the rapidly moving target, then provides the required missile course.

The second factor, a coordinate system for the missile circuits, is supplied by the beam in the form of special guidance signals. These are added to the other emissions of the radar and serve as markers which identify the positions of the beam as up, right, down, and left, with respect to the scan axis. An example is given in figure 5–4, which illustrates a system in which the guidance signals are dual

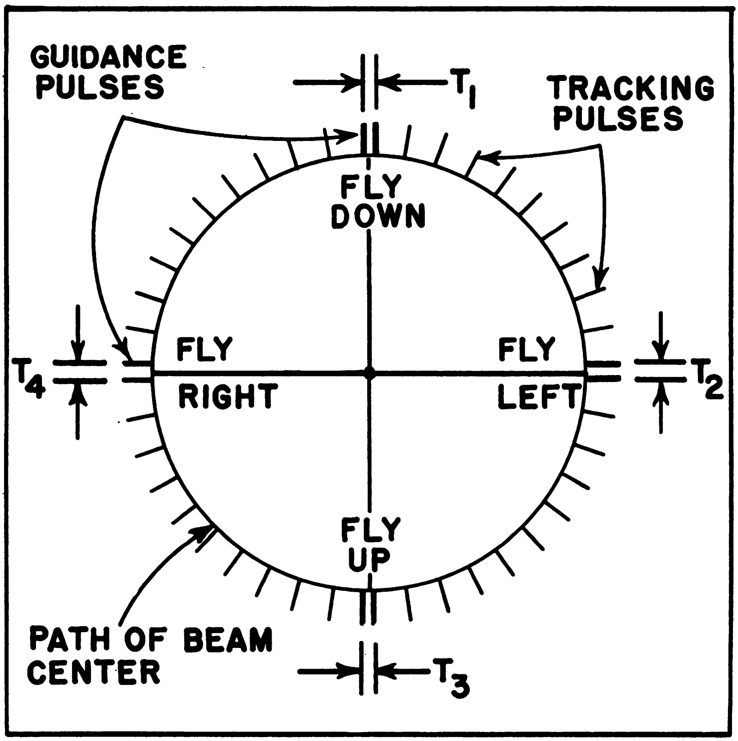

Figure 5–4.—Tracking and guidance pulses.

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pulses emitted at regular intervals during the circular sweep of the beam.

In the figure, the path of a point on the radar beam is represented by the circle, which is traced some 50 or 60 times per second to accomplish the scanning process. The missile guidance signals, which supply the required space reference system, are the four sets of dual pulses emitted during each scanning cycle and which divide the circle of scan into four equal sectors. Occurring at a much higher rate than the guidance signals are the tracking pulses, the regular emission of the fire control radar, which are returned as target echoes and so enable the tracking equipment to keep the circle of scan centered on the object of interest.

The tracking pulses, which are so essential in the overall operation, supply no information directly to the circuits of the missile. These operate solely under the direction of the dual guidance pairs. When received by the weapon, the guidance signals can be identified and one set distinguished from another, since in each pair, the two pips are separated by a different time interval. For example, the leading edges of the pulse pairs labelled T_1 might be separated by an interval of one microsecond; while, the remaining pairs, T_2, T_3, and T_4 might be spaced at two, three, and four microseconds respectively. Upon reception, the various pairs can then be identified by the time intervals involved and separated into four groups of signals corresponding to FLY DOWN, FLY UP, FLY LEFT, and FLY RIGHT.

An interesting feature of the system illustrated in figure 5–4 is that the positions of the guidance pulses are stabilized in space, even though the fighter plane should roll and change the position of the antenna emitting the signals. The stabilizing process is accomplished by a free gyroscope in the fire control system. When the aircraft rolls, the transmitted guidance pulses do not roll with it; but by means of signals supplied by the free gyro, the pulses are shifted around the scanning circle by an amount equal to the roll of the plane and in a direction opposite to it. As a result, each dual pulse set retains its original position in space.

A corresponding free gyro in the missile takes into account

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any roll of the weapon's airframe so that a common reference system is maintained in both vehicles. Although the dual pulses are identified as FLY DOWN, FLY UP, FLY LEFT, or FLY RIGHT, their actual positions in space are fixed by the roll attitude of the fighter plane at launching since they are stabilized in the positions present at that moment.

The double-pip signals illustrated in figure 5–4 represent only one of several forms used in beam-rider systems for conveying information to the missile. In some, the controlling radar supplies the FLY DOWN, FLY UP, FLY LEFT, FLY RIGHT reference data by frequency modulating the tracking pulses. The pulse rate, or pulse repetition frequency, is varied periodically and completes one cycle of change while the radar beam is sweeping once around the scanning circle; hence, the various positions of the beam can then be identified at the missile by the instantaneous frequency of the signals received. In other systems, single rather than double pulses are transmitted, and each of the four key positions on the scan circle is associated with a particular pulse width. While the details of the circuits differ according to the kind of signal supplied by the companion radar, the missile equipment operates along the same general lines in each case; and the principle involved can be easily understood by using an example based on time-coded dual pulses.

The missile circuits use the guidance signals to find and follow the correct course by the method illustrated in figure 5–5. In the process, the radar signals are received and demodulated; and the resulting pulses are separated according to the time spacings into four channels. After considerable amplification, the signals corresponding to opposite positions on the scanning circle are compared; that is, FLY DOWN signals are matched with FLY UP, and FLY LEFT with FLY RIGHT. The relative amplitudes of the voltages indicate the position of the missile with respect to the scanning circle; and the comparison of signal strength serves as a basis for producing the appropriate wing commands when the heading needs to be corrected.

Consider the case shown in (a) of figure 5–5 when the missile is flying along the scan axis. It is then equidistant

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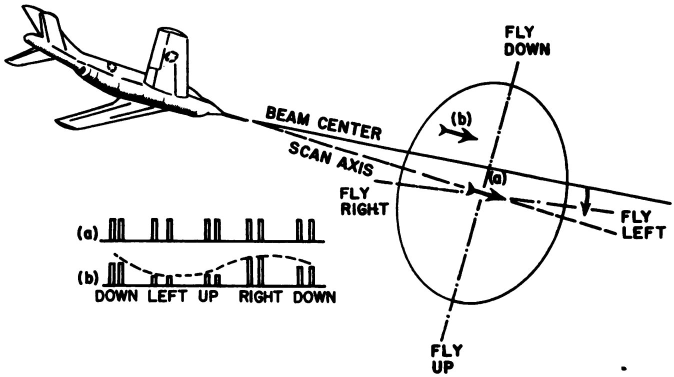

Figure 5–5.—Guidance by coded pulses.

from the beam positions at which all guidance signals are transmitted, and all four are received with equal strength. The guidance circuits produce no wing command in this case since no correction is necessary or desirable.

When the missile swings from the proper course, as in (b) of the figure, it is then nearer the beam when the FLY DOWN pulses are transmitted than when the FLY UP signals occur; hence the former are received in greater strength. Also, the FLY RIGHT pulses are stronger than the FLY LEFT pair. After comparing the opposite sets, the guidance circuits respond to the inequalities by developing two wing-command voltages. These mean "fly down" and "fly right" to the servo system, and they are put into effect by the wing-actuator units until the guidance pulses are again received in equal strength. This signifies that the missile has regained the course and is following the scan axis to the target.

The Guidance Components

The process illustrated in figure 5–5 is carried out by the guidance components, which, like the autopilot units, supply two types of control. The first, which controls the heading of the missile, acts to reduce its displacement from the scanning axis by governing lateral movements about the pitch and yaw axes. The other, the roll axis control, banks the missile to obtain maximum lift from the wings and to

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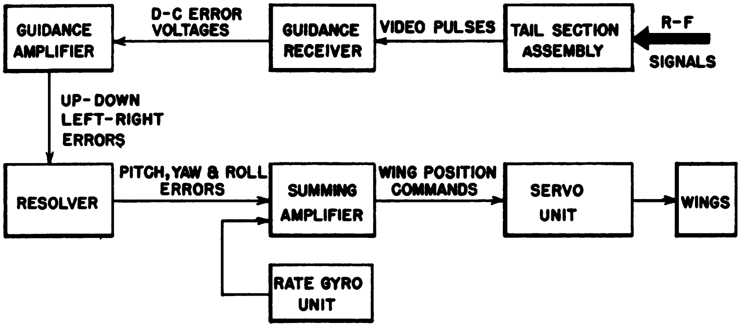

Figure 5–6.—Guidance system components.

equalize the lifting forces over the wing surfaces. The guidance components providing these types of control are shown in figure 5–6.

The system represented in the figure is suitable for operation with dual pulse guidance signals. The radar pulses are converted into pitch and yaw error signals delivered to the input of the summing circuits by the actions of four sections not used in the autopilot phase. These are the TAIL ASSEMBLY, the GUIDANCE RECEIVER, the GUIDANCE AMPLIFIER, and the COMPONENT RESOLVER. The output pitch and yaw voltages are combined in the summing circuits with damping signals from the rate gyro section shown in the figure to form the wing position commands, which are converted into wing deflections by the servo system. The summing amplifier and the servo units are the same components which were active in the autopilot phase.

In the guidance phase, the missile is not continuously rolled as in the thrust phase, but is rolled so as to aline some reference point on the airframe (such as the umbilical plug) with a line from the missile to the scanning axis. In the system in figure 5–6, roll control is achieved by comparing the pitch and yaw signals developed. The difference between the two then becomes the roll error signal. When the missile is displaced from the beam so that the pitch and yaw signals are equal in amplitude and opposite in phase, the roll signal is then zero. However, if its roll attitude is

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such that one error signal is greater than the other, a roll error voltage is obtained. This causes the weapon to roll until the pitch and yaw errors become equal in amplitude and opposite in phase and the roll error becomes zero. The roll signal is combined with a damping signal from the roll rate gyro to prevent oscillation about the longitudinal axis.

As indicated in figure 5–6, the conversion of the guidance pulses to pitch, yaw, and roll error voltages begins with the reception of the r-f radar emissions by the tail section of the missile.

THE TAIL SECTION ASSEMBLY.—The beam-rider tail assembly contains rear-facing waveguide antennas—usually four in number, arranged in the manner shown in figure 5–7. Each antenna is equipped with a crystal-detector circuit which rectifies the superhigh-frequency radar pulses received, converting them into video pulses. A T–R switching tube associated with each antenna-detector assembly protects the sensitive crystal from burnout when the missile is near the transmitting antenna during launching. The T–R tubes short out pulses of magnitude large enough to damage the crystals but pass the smaller pulses received during beam-rider operation. The output circuits of all the detectors are paralleled, and the signals produced are combined and applied to video amplifiers contained in the assembly. After passing through the amplifiers, the signals are then connected to the next stage, the guidance receiver.

THE GUIDANCE RECEIVER.—This section of the system shown in figure 5–6 separates the video pulses and applies

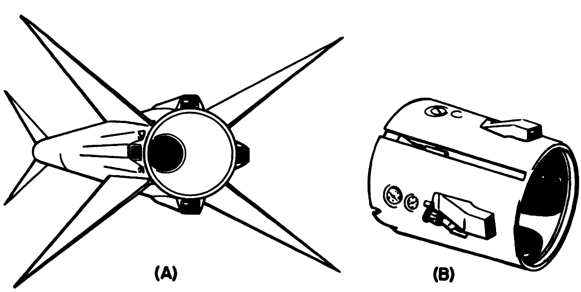

Figure 5–7.—Beam-rider tail assembly.

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them to the FLY DOWN, FLY UP, FLY LEFT, and FLY RIGHT channels. The process is carried out by means of more video amplifiers, a demodulator, and a group of filters.] After receiving considerable amplification in the receiver video circuits, the pulses are separated by demodulators, the output of each is then filtered, resulting in four d-c voltages. Each of these is proportional to the amplitude of the guidance pulses received in one of the four positions of the radar beam at which guidance emissions are sent. A simplified block diagram of a demodulator designed for separation of dual guidance pulses is shown in figure 5–8.

The sorting, or separating, process is accomplished by the use of four sections of delay line and four coincidence tubes. The delay sections are segments of an artificial transmission line composed of capacitors and inductance coils. The significant property of each section is the time required for an applied pulse to travel through it. In the circuits considered, the delay intervals provided by all sections are equal. The total delay presented to a signal equals the number of sections through which it has passed, multiplied by the delay of each section. In this manner a delay corresponding to the spacing of each of the pulse pairs illustrated in figure 5–4 may be obtained.

The coincidence tubes are pentodes which will conduct only when two of the tube elements are driven positive simultaneously. As shown in figure 5–8, the incoming video voltages are applied to the plates of all four tubes and to the delay line at the same moment. Consider the action

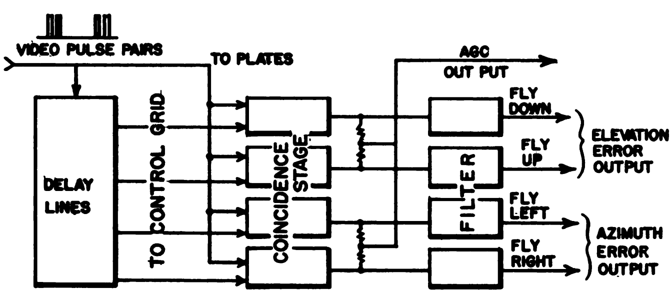

Figure 5–8.—Block diagram of demodulator circuits.

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of an applied pulse pair with a time interval of two microseconds. The first pulse of the pair will not cause any of the tubes to conduct but will travel down the delay line. At the moment the time-coded second pulse arrives at the plates two microseconds later, the first pulse will then be driving the control grid of one of the tubes positive. This tube is the one whose control grid is attached to the two-microsecond section of the delay line. This tube alone will conduct this pulse pair since its plate is then being driven positive by the second pulse while its control grid is the only one being driven positive by the first pulse.

By the same action, each of the other pulse pairs are conducted through one of the coincidence amplifiers and only one, so that each tube conducts signals of one time spacing only. The filters following the pentodes are employed to smooth the pulse signals into d-c voltages proportional to the amplitude of the received pulses. These voltages contain the error information which is applied to the next section.

The automatic-gain-control voltage derived from the demodulator output is fed to the grids of the video amplifiers in the receiver section where it adjusts the gain of the stages in accordance with the strength of the signals received. In this way, the output power level at the demodulator is kept constant as the missile recedes from the launching aircraft and the r-f signals diminish in strength.

THE GUIDANCE AMPLIFIER.—The function of the guidance amplifier is to convert the four varying d-c error voltages from the guidance receiver into two amplitude modulated, a-c signals, the "fly down, fly up" and the "fly left, fly right" errors. These voltages represent the vertical and horizontal displacements of the missile from the radar scanning axis.

The amplifier unit contains two identical channels. In one, the "fly down" and "fly up" d-c signals are combined to give a resultant voltage proportional to the net vertical error. This voltage is then used to modulate the output of an oscillator to convert the error information into an a-c form. The amplitude of the resulting modulated wave corresponds to the magnitude of the error involved; and the

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direction of the vertical error, either up or down, is indicated by the phase of the wave. By a similar process, the "fly left" and "fly right" d-c error values are converted into an a-c horizontal signal. The change of the information from d-c to a-c is required because of the nature of the next section, which is a special type of transformer.

THE COMPONENT RESOLVER.—The component resolver converts the up-down and right-left error signals from the guidance amplifier into pitch and yaw error voltages, which are related to the position of the missile wings, and thus are suitable for controlling the pitch and yaw control surfaces. The resolver contains two sets of dual windings, one of which is fixed to the missile frame and rotates with it. The other windings remain stationary regardless of missile roll, being held in position by the gimbal ring of a free gyroscope. The degree of magnetic coupling between the two sets of coils depends upon the angle at which one is turned to the other. Therefore, the up-down and left-right error signals, which are applied to the primary coils induce voltages into the secondary which are functions of the roll angle of the missile. These voltages form the pitch and yaw error signals.

The function of the component resolver is illustrated vectorially in figure 5–9. The total displacement of the missile from the beam-scanning axis is represented by the vector labelled "total error." With respect to the horizontal and vertical axes provided by the radar guidance signals, the total vector is the sum of the two components, the up-down and the right-left vectors. Voltages proportional to these are applied to the primary windings of the resolver by the guidance amplifier. And two new voltages are induced into the secondary which are proportional to the pitch and yaw displacement errors shown in figure 5–9. The pitch and yaw vectors add to give the same resultant total error, but are referred to a new set of coordinate axes, those formed by the wings themselves. The error voltages in the output are then proportional to the amount of deflection which must be given the corresponding wings in order to reduce the total error to zero.

The two signals developed at the output of the component

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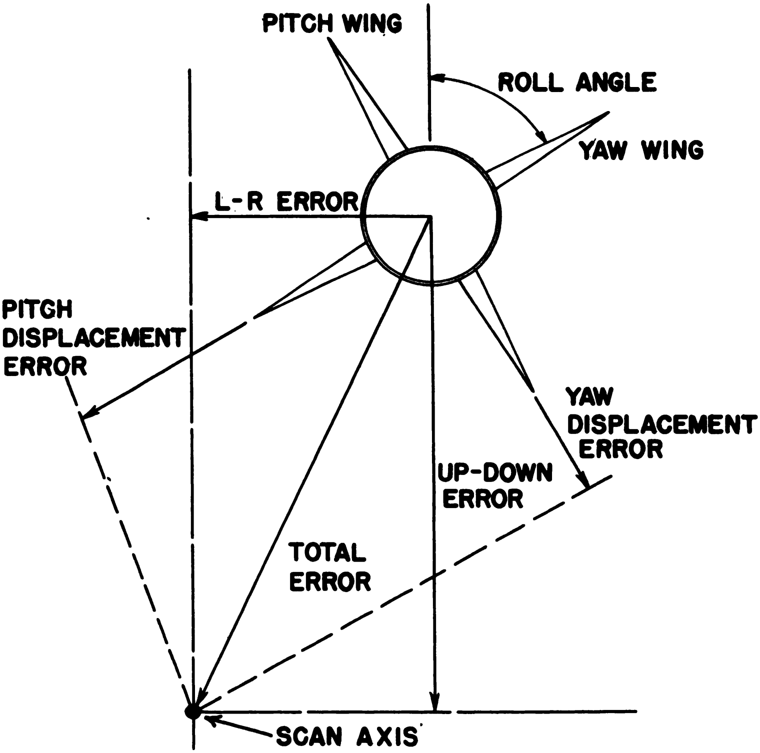

Figure 5-9.—Error signal resolution.

resolver are applied to the pitch and yaw channels of the summing amplifier, where they are combined with the outputs of two corresponding rate gyros. The resultant signals become the pitch and yaw error signals which are applied to the servo system. The third signal required, the roll error, is developed by applying the pitch and yaw voltages to a resistance network in the roll channel of the amplifier. Here, a voltage equal to the difference of the two signals is developed and used as the roll command voltage. It is combined with the output of the roll rate gyro and the resultant becomes the roll error command which governs the rotation of the airframe.

As in the autopilot function, the rate gyro output voltages

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are proportional to the missile's rates of turning about the three independent axes of pitch, yaw, and roll. These voltages are employed as feedback signals by the summing circuit, and their combination with the error voltages provides a means of damping the response of the missile, thus preventing oscillation about the required course. After the various voltages have been summed, the error signals are demodulated, amplified in the servo amplifiers, and applied to the control valves of the hydraulic wing units thus operating the wings in accordance with the guidance signals emitted from the fighter radar and steering the weapon along the scanning axis to collision with the enemy target.

As shown in the discussion above, the techniques of radar form the basis of the operation of the beam-rider missile. A system is considered next in which radar plays no part and in which the basic functions of guidance are carried out by means of radio control.

COMMAND SYSTEM

A command guidance system is similar to a beam-rider system in that the missile is controlled by the launching aircraft. In a command system however, the missile does not develop the steering commands but receives them directly from the parent aircraft. The command receiver merely converts the signals into the proper form to energize the servomechanisms which move the wings. A typical command system used for air-launched missiles is that in which a control operator in the launching aircraft visually tracks the missile and transmits control signals to keep the weapon on the line of sight to the target.

The control signals are usually conveyed to the missile by a radio command system employing frequency modulation, the principal components of which are shown in figure 5–10. (The principles of frequency modulation are discussed in chapter 8 of *Basic Electronics*, NavPers 10087.) The missile is guided by the operation of switches located on the CONTROL UNIT in the aircraft. Each switch corrresponds to a particular command, such as fly down, fly up, fly left, or fly right; and when operated, it connects power to one of several

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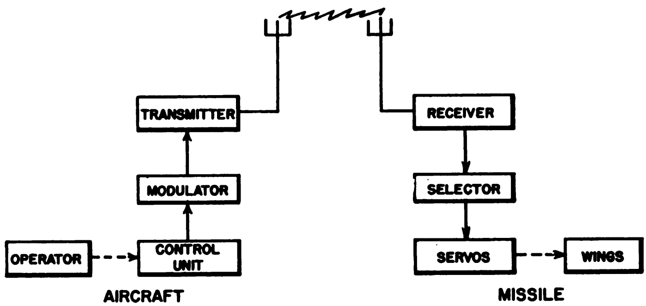

Figure 5–10.—Radio command system.

audio oscillators in the MODULATOR UNIT. Each oscillator generates a signal at a frequency chosen for a particular command, and the signal is applied to the input of the TRANSMITTER. Thus, the output of the modulator will be a different frequency for each command.

The signal from the audio oscillator modulates an r-f signal which is generated in the transmitter, and the modulated signal is fed to the antenna where it is radiated to the missile. The frequency-modulated carrier is picked up by the missile antenna and coupled to the RECEIVER where it is amplified and demodulated so that the audio frequency is separated from the r-f. The audio command signal is then fed to the selector where it is applied to the correct flight-control channel according to its frequency.

The basic units of the missile guidance equipment are shown by the block diagram in figure 5–11. The missile receiver is essentially the same as the f-m superheterodyne receiver discussed in chapter 12 of *Basic Electronics*, NavPers 10087. Its general operation is as follows: The amplitude of the incoming r-f signal is increased in the r-f stages; then the frequency is reduced in the mixer stage to the intermediate frequency and amplified in the i-f amplifier section. The amplitude of the i-f signal is then clipped in the limiter stage to remove any amplitude modulation. And the audio-frequency modulation is removed by the discriminator, then amplified by the audio amplifier stages and fed to the selector.

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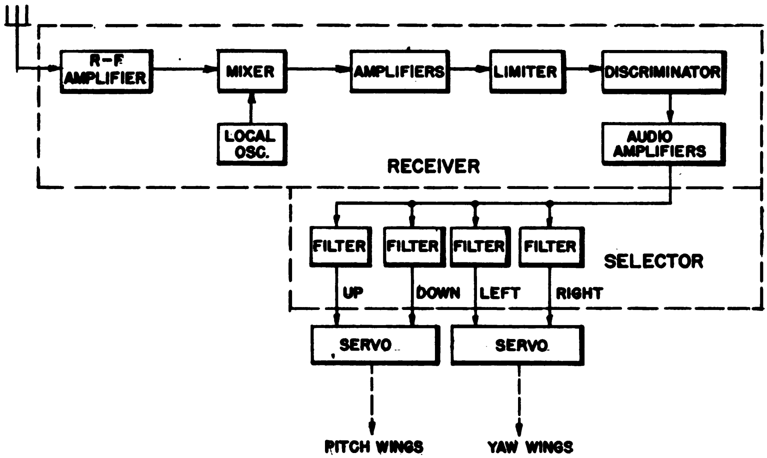

Figure 5–11.—Missile components for command guidance.

In the selector section, the audio signals are separated by filters. Each filter is tuned to one of the audio command frequencies; and because of the selective nature of the filters, each audio signal will pass through only one of them. When a command signal has passed through the corresponding filter, it energizes a relay which activates a wing-control servo, thus causing the desired maneuver.

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QUIZ

1. An early system of rocket control operated by means of ________ energy.
   a. heat
   b. light
   c. radar
   d. radio

2. The technique primarily responsible for present-day accuracy in missile beam guidance is ________ of targets.
   a. automatic tracking
   b. long range detection
   c. early identification
   d. large size

3. Which of the following supplies missile electric power before launching?
   a. Missile
   b. Aircraft
   c. Not used
   d. Missile and aircraft both

4. Before launching, power is supplied to
   a. vacuum-tube filaments
   b. TR tubes
   c. gyroscopes
   d. all of the above

5. Correct launching range is determined by
   a. radar computer
   b. pilot
   c. missile
   d. target speed

6. During missile flight, the gyros are
   a. caged and energized
   b. uncaged and energized
   c. caged and unenergized
   d. uncaged and unenergized

7. The two phases of operation after the beam-rider missile leaves the aircraft are usually
   a. thrust and detonation
   b. guidance and detonation
   c. thrust and guidance
   d. launch and guidance

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8. At the instant of motor burnout the missile is flying at its ——— speed.
   a. slowest
   b. fastest
   c. normal
   d. stalling

9. Throughout the flight of most beam-rider missiles, which of the following is usually controlled?
   a. Pitch
   b. Yaw
   c. Roll
   d. All of the above

10. A/an ——— senses changes in heading of the missile during the thrust phase.
    a. accelerometer
    b. gyroscope
    c. servo system
    d. radar beam

11. The two methods of control usually utilized in autopilot operation are
    a. yaw and roll
    b. pitch and yaw
    c. pitch-yaw and roll
    d. pitch and roll

12. The principal difference in the operation of the summing and servo sections of the missile in thrust and guidance is the ——— of signals applied.
    a. size
    b. source
    c. phase
    d. action

13. Roll control during thrust
    a. increases stability
    b. increases speed
    c. is always inoperative
    d. is detrimental

14. Deflection of one of a pair of wings in the opposite direction from the other results in a ——— movement.
    a. pitch
    b. yaw
    c. roll
    d. all of the above

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15. The path that the missile will fly during the guidance phase is
    a. predetermined before the missile is launched
    b. established by the free gyros
    c. defined by the tracking radar
    d. determined by the missile trajectory

16. The fire control radar must track the target and
    a. provide a signal for missile warhead detonation
    b. provide a coordinate system for the missile circuits
    c. furnish the missile accurate range information
    d. furnish the missile a roll signal

17. The missile identifies the guidance pulses in the guidance beam by
    a. the time between pulses
    b. measuring the amplitude of pulses
    c. phase discrimination of corresponding signals
    d. amplitude detection of succeeding signals

18. The guidance pulses are stabilized with reference to
    a. the missile axis
    b. the launching aircraft axis
    c. a free gyro in the launching aircraft
    d. the ground

19. To enable the missile to have the same reference as the launching aircraft, a/an__________is used in the missile.
    a. rate gyro
    b. free gyro
    c. accelerometer
    d memory circuit

20. When the missile is in the center of the beam,
    a. the left signal cancels the up signal
    b. the combined up-down cancels the left-right
    c. no signals are received within the missile
    d. all four signals are received with equal strength

21. When the missile is directly above the center of the beam, it will develop a__________signal.
    a. fly down
    b. fly up
    c. fly down and right
    d. fly up and left

22. The guidance components supply signals which control the missile
    a. roll rate only
    b. longitudinal acceleration
    c. heading
    d. speed of response

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23. The section that converts wing-position commands into wing deflection is the
   a. guidance amplifier
   b. guidance receiver
   c. component resolver
   d. servo system

24. During the guidance phase a roll signal may be generated by
   a. comparing the pitch and yaw signals
   b. a constant fixed input signal
   c. a proportional output from the rate gyro
   d. comparing the up-down and left-right signals

25. The tail section assembly receives, detects, and__________the radar signals received by all antennas.
   a. separates
   b. decodes
   c. phase discriminates
   d. combines

26. When separating pulses for guidance information, the demodulator uses a delay line and
   a. video amplifiers
   b. multivibrators
   c. coincidence tubes
   d. detectors

27. If no signal passes through the first section of the delay line,
   a. the demodulator will work regardless
   b. the coincidence tubes cannot conduct
   c. up-down signals will not be demodulated
   d. left-right signals will be correctly demodulated

28. The phase of the a-c signal from the vertical guidance amplifier corresponds to
   a. the amplitude of the error in one plane
   b. how far the missile is off beam center
   c. the direction of the vertical error
   d. the phase of the horizontal error

29. The component resolver has one set of windings fastened to the missile airframe; the second set of windings are
   a. fastened to the missile body
   b. controlled by a rate gyro
   c. used with an accelerometer
   d. positioned by a free gyro

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30. The component resolver converts signals from__________reference to__________reference.

a. missile; wing
b. beam; missile-wing
c. missile-wing; gyro
d. gyro; beam

31. The output of the rate gyros are fed back and used as__________ signals.

a. error
b. amplifying
c. regenerative
d. stabilization

32. The system employed in command guidance usually employs __________modulation.

a. phase
b. amplitude
c. frequency
d. pulse

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CHAPTER 6

HOMING SYSTEMS FOR AIR-LAUNCHED MISSILES

INTRODUCTION

All methods of missile guidance have the characteristic of becoming less accurate as the missile moves away from the source of control information. Conversely, a guidance system becomes more accurate as it approaches the source. Homing guidance systems represent the latter condition, as they use the target as the source of the guidance signals, as mentioned in chapter 2.

There are two ways in which the target can supply this information—by its natural radiations, or by reradiation when illuminated by some outside source of energy. If the target emits natural radiations that can be detected, a passive homing system may be used; but if it is necessary to illuminate it, either active or semiactive guidance is required.

This chapter contains a discussion of each of these basic types. The examples used illustrate some of the principal techniques and processes in both pulse and c-w radar homing as well as in infrared systems. In addition, a short section is included describing the proportional navigation course which is usually employed in homing guidance.

PROPORTIONAL NAVIGATION

In order to intercept high-speed targets, a missile must follow a lead course which results in an intersection of the missile and target paths. A lead course is necessary because the high turning rates required for a pursuit course cause excessive lateral accelerations. The best collision, or lead, course occurs when the missile heading maintains a constant

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angle with the line of sight to the target. This course requires missile accelerations to be only as great as target accelerations. In particular, if the target flies a straight-line, constant-velocity course, the missile can also follow a straight-line, collision course if its velocity is constant. Missile velocity seldom remains constant, however, since the missile is usually accelerated to supersonic speeds after launching from the aircraft, and then coasts for the remainder of the flight; and the missile path will often have to be adjusted to maintain a constant bearing with the target.

If the missile path is changed at the same rate as the changes in target bearing (see (A) of fig. 6–1), the missile will have to turn at an increasing rate (positions 1 to 6), and will end up chasing the target (positions 6 to 7). This path follows a pursuit curve and the missile cannot maintain a constant bearing with the target since it is just keeping up with the changes in bearing.

To achieve the desired straight-line course during the final and critical portion of the attack, the missile must turn at a rate greater than the rate at which the line of sight is turning. By overcorrecting the missile path in this way, a new collision heading is reached in which the bearing angle will remain constant and the missile will intercept the target on

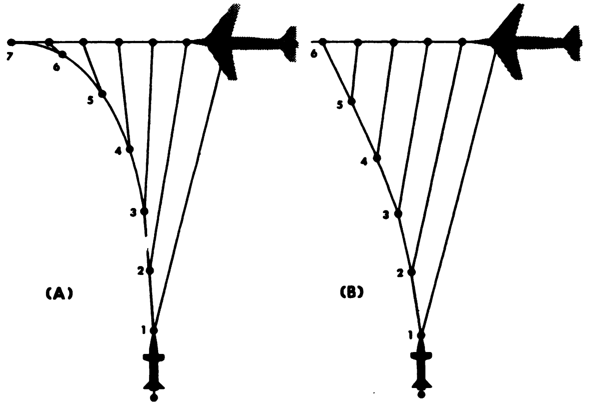

Figure 6–1.—Course correction for changes in target bearing. (A) Equal correction; (B) overcorrection.

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a collision course. This type of control is shown in (B) of figure 6–1. The ratio of the rate of turn of the missile to the rate of turn of the line of sight (rate of change of target bearing) is called the NAVIGATION RATIO, and is usually in the order of three to four.

This technique of overcorrection results in a course called PROPORTIONAL NAVIGATION which is an important characteristic of homing guidance systems. An excellent example of a guidance system which employs proportional navigation is the active radar homing method discussed in the following section.

ACTIVE HOMING SYSTEMS

Active homing systems illuminate the target and obtain the guidance information from the reflected signals by means of equipment located entirely within the missile. The type of equipment used in any particular system will depend largely on the location, speed, and maneuverability of the intended target. Active homing guidance may be used against both aerial and surface targets, and usually employs radar techniques to obtain the guidance information.

The arrangement of the components of a typical active homing missile is illustrated in figure 6–2. A homing radar is located in the nose section, and the antenna assembly is covered by a radome, The autopilot section contains the stabilizing devices, such as gyroscopes and accelerometers, and the electronic circuits that generate the signals which move the wings. The wing section consists of four movable wings and a hydraulic system for controlling their movement. The hydraulic oil is stored under high pressure in an accumulator and is supplied to the control linkages by electrically

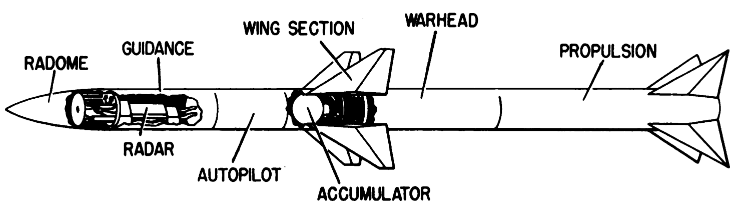

Figure 6–2.—Components in active homing missile.

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operated valves. The propulsion section contains a solid-propellant rocket motor, and supports four stabilizing fins.

Air-to-Air System

The microwave pulse radar set described in chapter 4 (fig. 4–11) is an example of the homing equipment employed in air-to-air missiles. This system controls the path of the missile on a collision course by constant-true-bearing navigation. It measures the target bearing with respect to a reference line which coincides with the line of sight to the target at launch (position A in fig. 6–3) and remains fixed in direction throughout the flight of the missile. The spin axis of the conically scanning antenna, which acts as a free gyroscope, serves as the reference line, and the amplitude modulation of the reflected echoes indicates the bearing of the target in both azimuth and elevation from the reference line.

During flight, the missile must keep the line of sight on the reference line to maintain the proper lead angle with the target. If the missile deviates from the correct path, or if

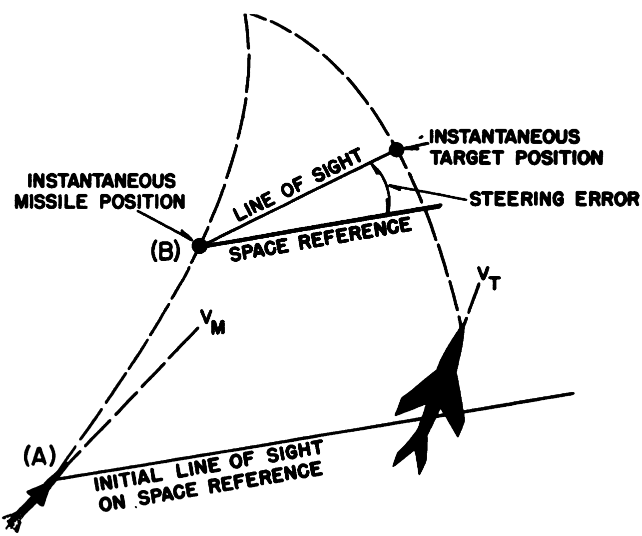

Figure 6–3.—Constant-true-bearing course.

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the target changes its course or speed, an angular error between the line of sight and the space reference will result, as shown at position B of figure 6–3. The direction of this error is determined by the target-position circuits which compare the amplitude modulation of the echoes with the antenna reference signals. With this target bearing information, the error-signal circuits generate steering commands, which are greater (by the navigation ratio) than the errors in the pitch and yaw axes of the missile. These commands are then sent to the control system to turn the missile so that the reference line is brought back onto the target.

Air-to-Surface System

An active homing system similar to those used in long-range air-to-surface missiles is illustrated in figure 6–4. A pulse radar automatically tracks the target in range and azimuth, and supplies yaw information to the control system to guide the missile on a pursuit course in azimuth by detecting any deviation of the missile's heading from the direction of the target. A radio altimeter supplies pitch information to the control system to keep the missile at a constant altitude until a preset range is reached when the weapon dives to the target.

AZIMUTH TRACKING RADAR.—The radar antenna is mounted in gimbal rings and is positioned in pitch and yaw by two drive motors which are controlled by gyroscopes so that changes in missile attitude do not affect its aim. In addition to this stabilizing function, the antenna gyro, when directed by signals from the error detector, causes the antenna to track the target in azimuth and sends antenna position signals corresponding to the relative bearing of the target to the control system.

The antenna contains two feed horns which are placed at equal distances from the focal point of the parabolic reflector. The pulses of microwave energy from the magnetron are fed simultaneously to both feeds; and as a result, the antenna emits two narrow beams whose directions differ slightly, as shown in the figure. The echoes received from each beam must pass through one of two switch tubes before

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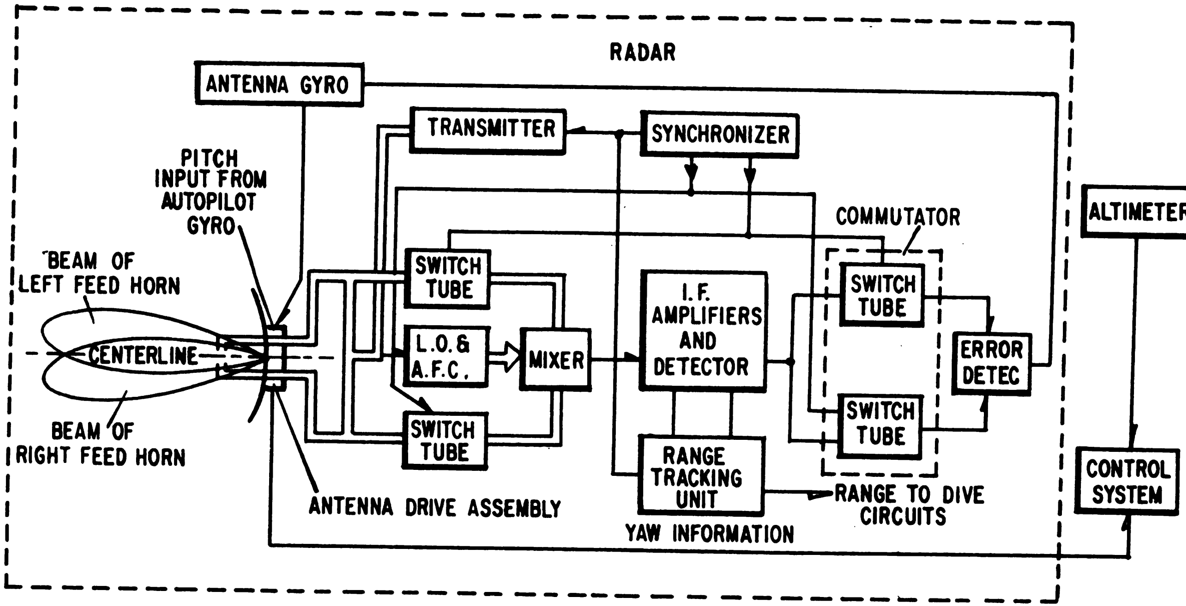

Figure 6-4.—ASM active homing system.

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entering the mixer. These tubes are controlled by the synchronizer so that the mixer and i-f stages receive signals from the left and right beams alternately with each pulse. After amplification and detection, the resulting video signals are fed to another pair of switch tubes which are also controlled by the synchronizer. These tubes conduct alternately, thereby commutating the video pulses into left and right signals which are fed to the error detector.

If the target lies on the centerline of the antenna, the echoes received from each beam will be equal in amplitude and there will be no output from the error detector. If the amplitudes are not equal, the error detector generates a signal which precesses the antenna gyro and turns the antenna until equal signals are received from both beams. A signal proportional to the relative bearing of the antenna is sent to the control system, which changes the missile heading so that it corresponds to the direction of the target; and thus, the missile follows a pursuit course in azimuth.

Altimeter.—The radio altimeter which supplies elevation information employs the f-m continuous-wave method of measuring the height of the missile above the terrain. The basic components of this unit are shown in the block diagram of figure 6–5. The sawtooth sweep generator causes the modulator to vary the frequency of the c-w magnetron at a constant rate. The r-f energy from the magnetron is radiated downward by a horn antenna, and the reflected signal is received by an identical horn. The reflected signal is compared with the instantaneous magnetron frequency,

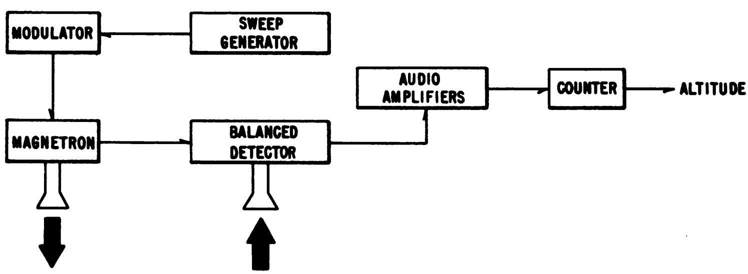

Figure 6–5.—F-m altimeter block diagram.

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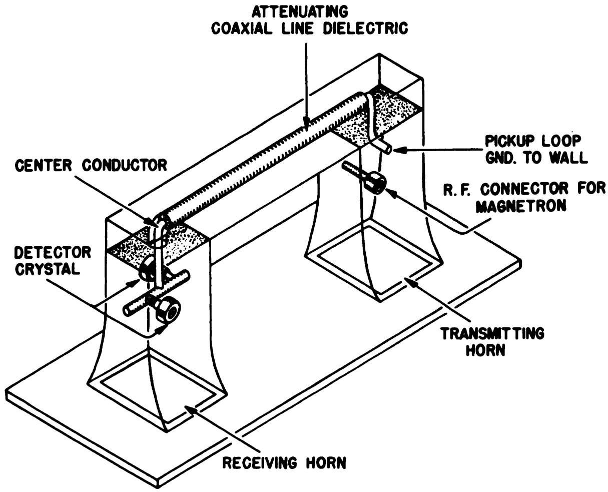

Figure 6–6.—Phantom view of altimeter r-f assembly.

which has changed during the time the received signal was traveling to the ground and back. The two signals are mixed in the balanced crystal detector so that the output is a difference frequency. (The r-f assembly containing the two horn antennas and the balanced detector is illustrated in figure 6–6.)

The rate at which the magnetron frequency is varied is such that at low altitudes the difference frequency is in the audio range and is proportional to the altitude. The balanced detector is followed by several stages of audio amplification and a counter, which supplies the control system with a d-c voltage proportional to the difference frequency, and hence the altitude. The altitude voltage is compared with a preset value to determine any elevation error in the missile path. When the altitude differs from the preset value, the resulting error signal causes the wing control system to deflect the control surfaces accordingly.

SEMIACTIVE HOMING

A missile employing semiactive homing guidance receives radiation reflected from the target, which has been illuminated from a source outside the missile. A receiving

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antenna in the nose of the weapon intercepts the reflected energy; and the guidance and control components cause the missile to home in on the object returning the echoes. The source of illuminating waves is usually a radar transmitter which, in the case of the air-launched weapon, is located in the parent aircraft. Thus, it is unnecessary that the missile carry the heavy, complex transmitting equipment required in the active homing weapon; while at the same time, it retains the principal advantage of homing guidance, that is, its accuracy increases during the final phase of the attack while closing on the target.

With the exception of originating the illuminating signals, the guidance sections of the semiactive missile perform the same essential functions carried out by most active homing systems. They select the target echo; locate and track the object; determine its line of sight; and develop error voltages for the autopilot in accordance with the position of the target and the rate of turning of the line of sight. In air-to-air semiactive systems, the missile is generally steered along a collision course with the target by the process of proportional navigation, in which the weapon is accelerated laterally at a rate greater than the rate at which the target line-of-sight angle changes.

In both active and semiactive radar homing systems, the missile receiving circuits must be capable of operating effectively with target echoes of very low intensity and must have exceptional selectivity. The signals by which the missile target seeker detects and tracks the target arrive by a two-way path. In the semiactive system, these emissions travel from the launching plane to the target object and back to the missile antenna; and during the journey, the radiation becomes considerably diminished in strength. Upon reception, the weak echoes may be nearly obscured by many competing voltages present at the receiver input or else generated within the receiver circuits. Among these are random noise voltages, clutter signals returned by the ground or sea, jamming transmissions from enemy countermeasures equipment, and in some instances, radiations from the turbine blades of jet engines. Before it can lock on and track

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the correct object, the receiver must select the corresponding echo singal in the presence of these interfering voltages, and hence must be able to discriminate against many false or undesired signals.

In this section, semiactive radar homing is illustrated by a system which achieves the high degree of selectivity and sensitivity required by means of continuous-wave (c-w) operation, a basic radar method ~~which~~ differs considerably from the pulse methods usually employed in beam-rider and active homing weapons. With c-w illumination of the target, the missile receiver detects the presence of the target object by sensing its relative speed, the principal measurement being one of frequency difference. The basis of this measurement is the Doppler effect, a property of wave motion which has numerous applications in many fields of physics. The general nature of this effect and the characteristics which make it useful in missile homing systems ~~are~~ considered here before describing a typical c-w semiactive missile.

The Doppler Effect

First brought to notice in 1842 by an Austrian physicist, Christian Doppler, the principle which now bears his name pertains to the shift, or change in frequency, that occurs when there is relative motion between the source and the receiver of a series of waves. The frequency shift takes place with all kinds of waves—with sound, light, and with the emissions of radio and radar transmitters. A simple example in terms of sound is familiar to anyone who has observed the change in pitch of a train whistle as it approaches or recedes rapidly. When approaching, the sound-producing whistle comes a little nearer between each two successive waves it emits; and the waves strike the ear in a little more rapid succession, so that the frequency becomes greater and the pitch rises.

If the train is moving away from the observer, the interval between successive waves is slightly increased, the frequency received by the ear is somewhat decreased, and the pitch is lowered as a result. If the frequency of the sound received when the train is at rest is measured and compared with the

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value received when the train is in motion, there is a difference in the two values called the DOPPLER SHIFT. This frequency difference could then be used to measure the speed of the train with respect to the observer.

A continuous-wave radar operates by means of the same effect except that electromagnetic waves are employed instead of sound. The transmitting antenna of the radar set beams uninterrupted, unpulsed energy of a given frequency upon the target. Upon reflecting the energy, the object becomes in effect a second emitter of waves; and if it is in motion with respect to the radar, the frequency of the returning echoes differs from that of the outgoing signals. The echoes are picked up by a separate receiving antenna and are heterodyned in the receiver with a small reference voltage at the frequency of the outgoing waves. The difference value, or beat frequency, which results from mixing the reference and echo voltages, is the Doppler signal, the presence of which indicates a moving target. And as in the example of the moving train whistle, the Doppler value in cycles per second serves as a measure of the relative speed.

In textbooks that deal with the Doppler effect, it is shown that in two-way travel of electromagnetic waves as in the c-w radar system, the amount of frequency change in cycles (f_D) is related to the relative closing speed (V_c) by a simple equation,

$$f_D = \frac{2V_c f}{c} \qquad \text{(eq. 6-1)}$$

in which f is the frequency of the reference signal, and c is the velocity of the radar waves. If the closing velocity is measured in miles per hour, and if $\frac{c}{f}$ is taken as the wavelength of the reference emission, the equation can be expressed in the following form:

$$f_D = \frac{89.4\ V_c}{\lambda} \qquad \text{(eq. 6-2)}$$

where f_D is in cycles per second, V_c is in miles per hour, and the wavelength, λ, is measured in centimeters.

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If the c-w radar emits radiation with a wavelength of 10 centimeters, then according to equation 6–2, the Doppler signal will vary by almost 9 cycles per second for each increment in the closing speed of one mile per hour. If the radiation has a wavelength of 3 centimeters, a typical value in microwave systems, then the Doppler shift amounts to almost 30 cycles per second for each increment in closing speed of 1 mile per hour.

The relation of signal frequency to velocity is illustrated in figure 6–7, which indicates the distribution of Doppler signals corresponding to three conditions of relative motion. The missile, employing c-w radar guidance, flies at a velocity of V_m. For the aircraft approaching at velocity V_1, the missile circuits produce a Doppler signal proportional in frequency to the sum of V_m and V_1. The signal of the crossing plane is considerably less in frequency, being proportional at the instant shown to the missile velocity, V_m. And the signal of the receding plane is determined by the difference between V_3 and the missile velocity.

With Doppler operation, the missile circuits are designed to exclude all signals except those contained in a fairly narrow frequency range called the SPEED SPECTRUM of the

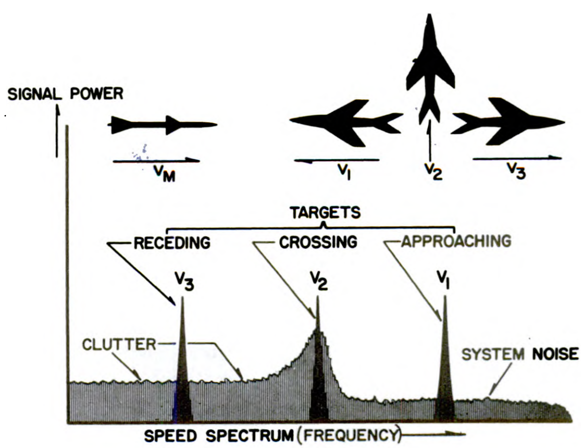

Figure 6–7.—Doppler signals for various closing velocities.

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system. This term refers to the range of Doppler frequencies corresponding to the possible closing speeds of the missile with the class of targets for which it is intended. For example, assume that for a certain air-to-air missile, the sum of V_m, the missile velocity, and V_1, the velocity of an approaching aircraft, is 2,000 miles per hour and that this figure represents the maximum closing speed of the missile and any possible aircraft target. Assume further that the minimum possible closing speed is 100 miles per hour; and also that the radar system employs 3-centimeter radiation.

When these figures are substituted in equation 6–2, the resulting Doppler frequencies are 59,600 c. p. s. for the upper speed and 2,980 c. p. s. for the lower—a range of approximately 3 to 60 kilocycles. The speed spectrum of this particular system would extend over a range including these and all intermediate frequency values, thereby including the Doppler frequencies of all valid aircraft targets.

The missile receiver contains frequency selective circuits that respond only to Doppler signals in the appropriate speed spectrum; and after selecting one target signal in this range, the tracking circuits lock on and track the corresponding object "in speed." By restricting reception to the comparatively narrow band representing possible closing speeds, all interference and clutter frequencies outside the band are eliminated at the outset. Furthermore, the likelihood of the missile being jammed by enemy countermeasures is minimized, the signal-to-noise ratio is increased, and the ability of the guidance receiver to work with low-level input voltages is improved.

However, not all interference can be eliminated by Doppler operation. Random noise, for example, occupies a frequency band which is extremely broad, and some noise energy necessarily appears in the speed spectrum. Also, as indicated in figure 6–7, some clutter return is present in the spectrum; although it usually occurs at frequencies lower than those of most aircraft Doppler signals and is easier to discriminate against than noise.

To insure selection of a valid Doppler signal against a background of interference, the following method is often

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employed in c-w missile systems. The carrier wave of the companion radar is modulated with at least two identifying, or coding, signals. One of these, when detected in the missile circuits, causes a section of the receiver to lock on the beam of the correct parent transmitter so that the proper reference frequency for producing the Doppler signals is assured. The second coding signal provides a means for selecting valid Doppler voltages. Gating circuits in the receiver scan the speed spectrum, examine each signal in turn, and determine whether or not the identifying modulation is present in sufficient strength to indicate an aircraft target. Noise voltages and other signals which do not contain the coding frequency are rejected, while the valid signal, which contains the modulation, is passed on to the tracking circuits.

The application of Doppler methods to missile homing has produced guidance equipment which is superior to most pulse radar sets for operations against low-flying targets because of the effectiveness of c-w radar in working through interference and clutter. Also, c-w radar is usually more accurate in angular tracking and is capable of operating effectively at ranges equal to or greater than those of pulse guidance systems of comparable average power. The general features of a semiactive missile system based on Doppler principles are described in the following pages. And since the "brains" of the system are divided between the launching plane and the missile, the components comprising the parent equipment are described in addition to those of the missile.

The Aircraft Equipment

The semiactive homing missile is suitable for use in day-fighter operations and may also be carried in all-weather interceptor aircraft. In the usual day-fighter installation, the pilot acquires the target visually and flies the airplane so as to keep the object in his gunsight. The essential companion equipment of the missiles contains (1) the illuminator radar, a small, low-powered, c-w system that provides no automatic aiming features but which includes both transmitting and receiving functions; (2) the launching equipment ~~consisting of finite-length launchers and pylons~~ for

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~~underwing suspension of the missiles~~; and (3) the necessary wiring and cabling, the cockpit controls and indicators, and the relays which operate the firing circuits of the weapons. The illuminator radar unit may be mounted in an external stores package such as a wing pod, or in the nose of the aircraft.

In all-weather fighter installations, the total equipment includes the same basic units except that the missile illuminator radar is an aircraft intercept (AI) system, either of the pulse type or else an f-m/c-w unit. In the pulse AI installation, illumination of the target with c-w radiation is accomplished by means of an auxiliary unit which injects the continuous-wave energy into the emissions of the pulse radar. The principal components of the installation which are associated with control of the missile are indicated by means of the simplified block diagram in figure 6–8, illustrating a typical f-m/c-w system.

Upon acquisition of the target, the f-m/c-w illuminator radar measures the closing speed and the target range and applies the information to the range interlock unit. Speed is determined by Doppler operation, and range is measured in the system shown by frequency modulation of the emitted waves. The process of ~~ranging is~~ similar in principle to the method employed in the radio altimeter described in the

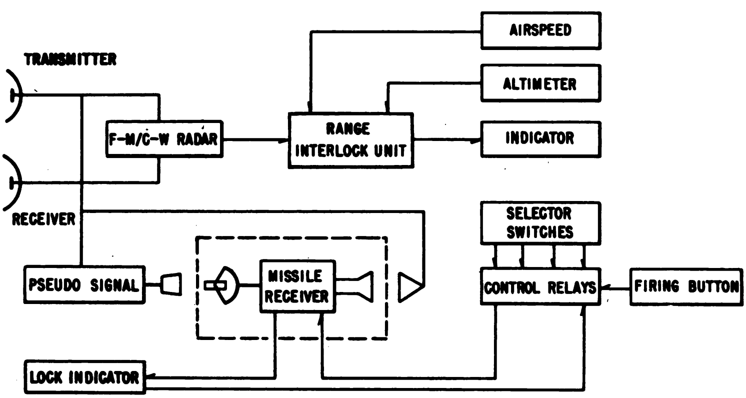

Figure 6–8.—Block diagram of illuminator installation.

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discussion of active homing and also to the f-m method discussed briefly in chapter 4.

The range interlock unit receives the radar information and combines it with altitude and aircraft airspeed data to determine if the target is within the zone of effectiveness of the missile. If within this zone, the interlock is closed, allowing the missiles to be fired.

While the weapons are on the launching racks, the guidance circuits are placed in operation and the receivers are locked on a "pseudo signal" generated by the parent radar system. Successful lock on this signal indicates proper operation of the missile guidance equipment and that the receivers are tuned to the illuminator emissions. Failure to lock on the pseudo signal by any missile will automatically hold fire on that particular weapon. When lock-on has been accomplished, a signal is applied by the lock indicator to the missile relays; and this voltage, together with the enabling signal from the interlock unit, permits the pilot's firing button to energize the firing circuits.

At launch, the missile guidance receiver loses the pseudo signal and will then begin automatic search for the target, receiving the c-w signals emitted by the illuminator radar both directly and by reflection from the object.

The Missile Target Seeker

The guidance and control equipment carried within the semiactive missile consists principally of a target seeker and an autopilot. The c-w target seeker, a special type of radar receiver, develops the signals required for steering the weapon. It searches for the reflected target signal, locks on, and tracks the object to produce the steering error voltages. In addition, it measures the closing speed of the missile and target and provides a voltage proportional to its value. The signals thus derived are applied to the units of the autopilot, which adjust the missile wings to bring about the necessary changes in course for steering the missile to collision. The major components of a representative target seeker employing Doppler operation are shown in block diagram form in figure 6–9.

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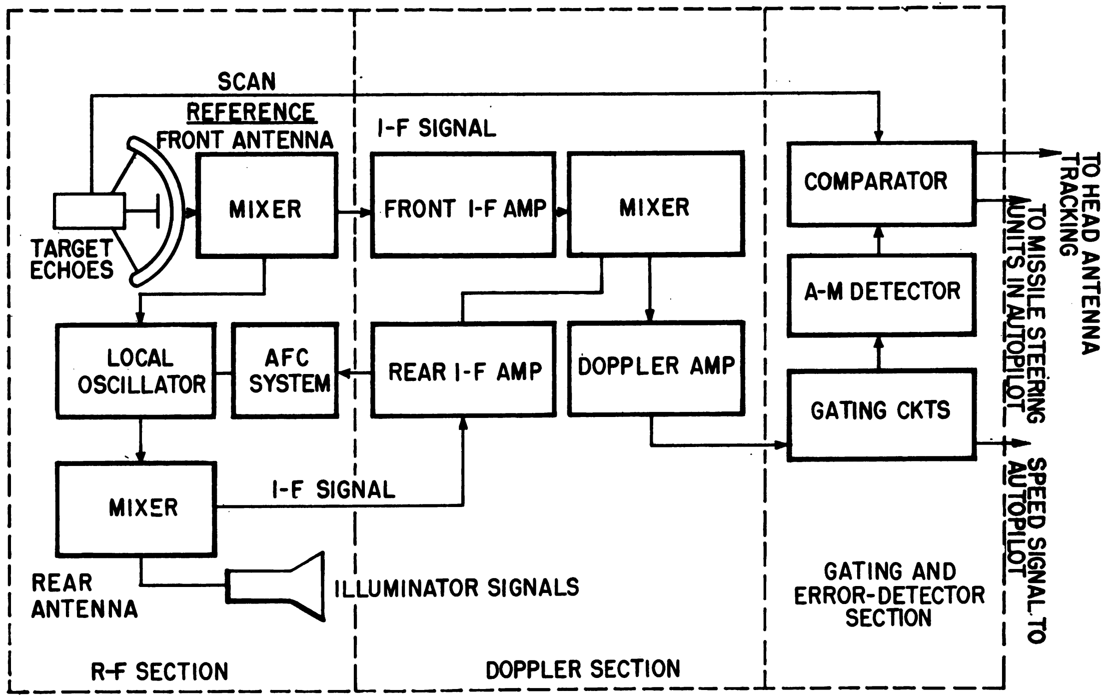

Figure 6-9.—Block diagram of a c-w target seeker.

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THE RADIO-FREQUENCY SECTION.—The r-f section of the seeker shown in the figure contains a forward-facing antenna, a rear-facing antenna, a local oscillator, two crystal mixers, an automatic-frequency-control system, and several sections of waveguide for conducting the superhigh-frequency energy received by the antennas. The antennas receive illuminating signals from opposite directions, and the associated circuits develop two independent i-f output voltages.

A sample of the illuminating waves is received directly from the parent radar through the rear antenna. This signal is heterodyned in one of the crystal mixers with the output of the local oscillator, a klystron. The resulting voltage at the difference frequency of the oscillator and the incoming waves is applied to the input of the rear i-f amplifier in the following section of the receiver.

The klystron oscillator searches by varying periodically in frequency until an i-f signal is obtained which has the identifying coding modulation of the companion radar. When this occurs, the AFC circuits lock the klystron frequency at the value required to receive the signal; and thereafter these circuits automatically adjust the local-oscillator frequency so as to retain constant reception of the illuminating waves through the rear antenna. These signals then serve as the basic reference frequency of the system.

The forward-facing antenna is a conically scanning receiving assembly that intercepts the radar echoes returned from the target. As indicated in the block diagram, the antenna is connected to a mixer in which the signals received are heterodyned with the output of the common local oscillator. The resulting voltage is the input for the front i-f amplifier.

The frequency of the signal received by the front antenna is shifted because of the Doppler effect and differs from the frequency of the rear-antenna reception by an amount proportional to the closing speed of the missile and the target. Both the echo and the reference reception are mixed with the output of the same oscillator; hence the two i-f signals resulting also differ in frequency by the same amount as the original receptions. This difference is the basis for develop-

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ment of the Doppler signal of the target which is produced by mixing the two i-f voltages. This process is carried out in the section following the r-f components.

Information concerning the azimuth and elevation angles of the target is provided by the action of the front antenna as it receives the radar echoes by conical scanning. A typical antenna assembly used for this purpose contains the following principal parts: A parabolic reflector in front of which is mounted a small, metal disk having three resonant slots; the servo units which adjust automatically the antenna position; and a small two-phase reference generator.

The slotted disk is the primary radiating element of the target seeker system. Reflected r-f energy from the illuminated target is captured by the parabolic reflector, focused on the trislot disk, and reradiated to the crystal mixer by way of a feed line.

Conical scanning is accomplished by varying the direction of reception of the assembly. This results when the slotted disk is rotated rapidly by a motor which also drives the reference generator. The reception pattern of the slotted disk and reflector can be visualized as a narrow lobe, or pencil, extending forward. As the disk revolves, the direction of maximum sensitivity rotates as well; and the pencil-like lobe of reception traces out a conical figure similar in shape to that generated by the beam of a conically scanning transmitting antenna.

As the receiving pattern varies in direction, sweeping over the surface of an imaginary cone, there are corresponding variations in the amplitude of the echo signals received unless the target is located on the scan axis. Upon reception, echoes from targets offset from the scan axis contain amplitude modulation, which indicates the position of the object. As outlined in the discussion of conical scanning in chapter 4, the amplitude and phase of the modulation envelope are determined by the target distance from the axis and its angular position. This modulation, which provides the required position information, appears later on the Doppler signal of the target and is extracted in another section of the target seeker. There it is converted into error signals for

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the autopilot and the antenna tracking units by comparison with the output of the two-phase reference generator included in the antenna assembly.

THE DOPPLER-SIGNAL SECTION.—In the system illustrated in figure 6–9, the two i-f signals produced by the r-f section of the receiver are amplified and applied to a mixer stage. The output of the mixer contains the target Doppler signal, or the difference frequency of the i-f voltages, in addition to many other voltages representing noise. The entire mixer output is applied to the input of the Doppler amplifier, a broadband stage, which is tuned so as to pass only the frequencies corresponding to the range of expected closing velocities, or the speed spectrum of the missile. Any amplitude variations of the input i-f signals are retained during mixing. As a result, the target Doppler signal contains the amplitude modulation present in the front i-f signal resulting from reception of the radar echoes by the conically scanning front antenna.

THE GATING AND ERROR-DETECTOR SECTION.—All signals passing through the Doppler amplifier (fig. 6-9) are applied to the input of the gating circuits. The principal functions of this system are to select the target Doppler signal in the presence of noise, lock on the signal, and pass it on to the error-detectors which derive the guidance error signals. In addition, the gating circuits also produce a control voltage which is a function of closing speed of the missile and target, and which is used for multiplication of the system navigation ratio.

There are many possible forms of gating systems, and only one, an automatic spectrum analyzer, can be described briefly here. The fundamental principle of operation of this system is somewhat similar to that of the analyzer test equipment discussed in chapter 13 of *Basic Electronics*, NavPers 10087; except that the missile circuits contain no visual indicators and include circuits for testing and locking on one of the signals present.

The essential operation of the system can be indicated by the simplified block diagram in figure 6–10. The input stage is a mixer to which the mass of signals from the Doppler

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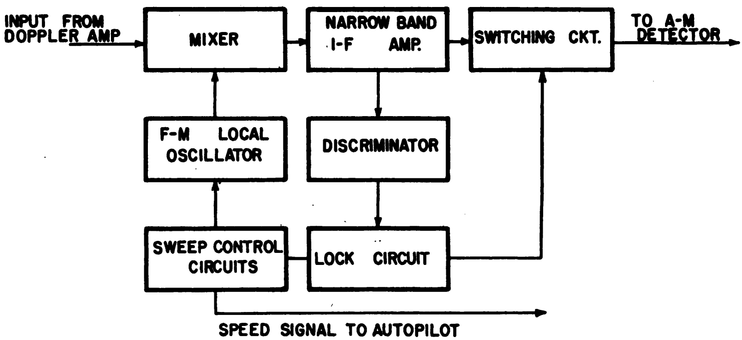

Figure 6–10.—Simplified block diagram of gating system.

amplifier is applied. Also applied to the mixer is the output of an f-m oscillator. The oscillator frequency is varied periodically under the control of the sweep circuits and changes linearly between two extreme values. The output of the mixer, consisting of beat frequencies of the f-m oscillator and the incoming signals, is applied to a tuned i-f amplifier. This stage has a very narrow pass band and accepts frequencies over a range of about 1 kilocycle. These basic units scan the speed spectrum and pass the signals through one at a time.

As the oscillator sweeps through its range, each instantaneous frequency beats with all the input signals present in the mixer. But at any given moment, only one of the signals combines with it to give the beat frequency acceptable by the tuning circuits of the narrowband i-f amplifier. During one cycle of sweep of the f-m oscillator, each incoming signal present forms the beat frequency required to pass through the amplifier at some instant of the cycle. Thus all incoming signals are converted to the i-f value and are separated in time, passing into the amplifier in the order of frequency.

Emerging from the i-f amplifier, each signal is applied to a discriminator, the output of which is tested for the presence of the coding modulation supplied originally by the parent transmitter. Detection of the identifying modulation indicates a valid target signal and causes the lock circuit to be activated. This action disables the sweep control tubes,

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stopping the f-m oscillator at that part of its cycle of change which permits the valid signal to be obtained.

If reception of the desired signal ceases, the system begins sweeping again and searches until the target is regained. After lock on by the gating circuits, a switching circuit is closed permitting the output of the i-f amplifier to pass through to the a-m detector. A voltage proportional to closing speed is taken from the control tube which governs the instantaneous value of the f-m oscillator.

The a-m detector removes the amplitude modulation representing the target position and the output is applied to the comparators, where it is compared with the two-phase scan reference voltages. After rectification, the useful output consists of d-c error voltages for steering the missile and for application to the servo units which control the tracking antenna.

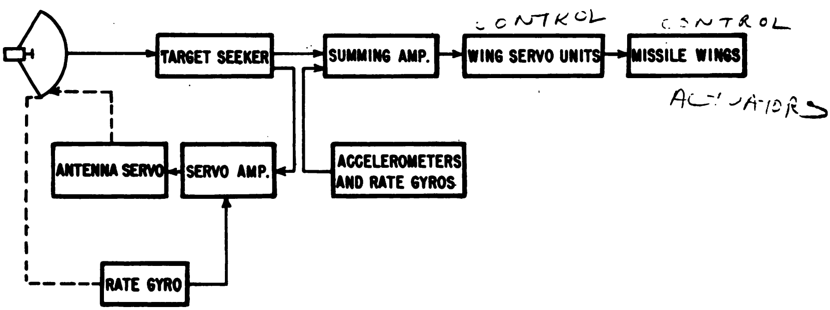

Figure 6–11.—Block diagram of control systems.

The major components of these two control systems are indicated in the block diagram in figure 6–11. In the autopilot, the error signals from the target seeker are combined in a summing amplifier with accelerometer and rate gyro signals, the latter providing feedback and stabilization voltages. The resultant is then amplified and applied to the wing servo units which adjust the missile wings.

In the antenna servo system, the error signals are amplified and summed with a rate gyro signal to produce the antenna command voltages which operate the antenna control units.

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These adjust the position of the front antenna so as to track the target automatically.

PASSIVE HOMING

Introduction

Passive homing equipment detects and tracks a target by sensing some type of radiation that the target emits. A passive homing system, like an active system, is completely independent of the launching aircraft, thus allowing the aircraft to maneuver immediately after firing the missile. Unlike the active method however, the operation of the passive equipment cannot be detected by the enemy since the target is supplying the guidance signals.

The most common type of radiation used for passive homing is infrared, which is produced largely by propulsion systems. However, in order to utilize infrared radiation as control information, there must be a distinct contrast between the target and the background; and the background must be reasonably uniform in temperature so that the target will be the only "hot spot."

Infrared System

Passive infrared guidance systems are usually automatic-tracking devices which provide information to the control units concerning the rotation of the line of sight. This information is the basis on which the control system steers the missile on a proportional navigation course to interception. Automatic tracking is accomplished by giving directional intelligence to the received signals and using this information to position the homing head so that the scan axis remains on the line of sight to the target.

One method of determining the direction of the target is by the use of an offset scanning mirror focused on cruciform bolometer flakes, as described in chapter 4. (See fig. 4–21.) The major components of a representative infrared homing system employing this type of optical scanning are illustrated in figure 6–12. While this system does not represent any

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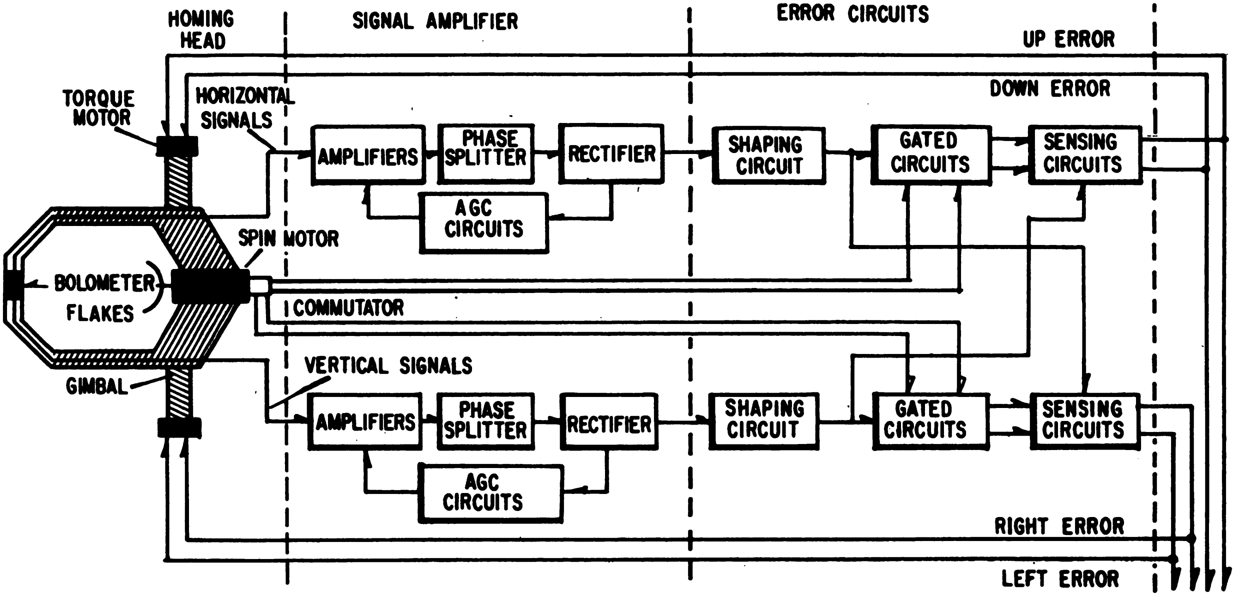

Figure 6-12.—Passive infrared guidance system.

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particular missile guidance equipment, it illustrates the basic functions and processes of passive infrared guidance.

HOMING HEAD.—As the mirror scans the target area, the thermal image of the target is reflected onto the flakes causing their resistance to change. When the resistance of each changes, the voltage at the junction of each pair will rise or fall depending on which flake is affected, thus transforming the infrared signals into electrical voltage pulses. These pulses are transmitted to the SIGNAL AMPLIFIER section as either vertical or horizontal information. The COMMUTATOR, driven by the mirror shaft, converts the two-channel signals into four channels of intelligence corresponding to UP, DOWN, LEFT, or RIGHT in the ERROR-DETECTOR section. The terms horizontal and vertical as used here refer to the signals developed by the vertically and horizontally positioned bolometer flakes, and do not necessarily imply that such signals will cause corresponding turning of the homing head. The exact designation of the intelligence is not available until the signals reach the sensing circuits in the error detector.

SIGNAL AMPLIFIER.—The function of the signal amplifier section is to amplify and rectify the pulse signals delivered by the bolometer so that only positive pulses of high amplitude are available at the outputs for the error detector. There are two complete channels in the signal amplifier and error-detector sections; one channel processes the signals from the horizontal bolometer flakes; the other uses the signals from the vertical pair. The two channels are identical and the discussion which follows may be applied to either of them.

The small voltage pulses from the bolometer flakes (usually a few millivolts) are increased in amplitude by a four-stage amplifier employing pentode and triode vacuum tubes. The bias on the pentode tubes is controlled by the AGC voltage to prevent the signals from becoming too large as the missile approaches the target. After amplification, the pulses are fed to a phase splitter, whose function is to provide two output pulses, equal in amplitude and opposite in polarity, for each signal pulse applied. These two output pulses are fed to a rectifier which selects only the positive

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pulses and passes them on to the error detector. Thus, for each pulse of either polarity applied to the phase splitter, a positive-going pulse appears at the output of the rectifier. In addition, the rectifier also supplies the positive pulses to the AGC circuits which regulate the gain of the amplifier stages.

ERROR DETECTOR.—The error detector separates the two channels of information (horizontal and vertical) into four channels (left, right, up, and down). From these it detects any error in the aim of the homing head and supplies signals which energize the torque motors to reduce the error to zero. It also supplies the signals to the control system, which makes the necessary changes in the course of the missile.

The signals of varying shape and amplitude received from the rectifier are first converted by the shaping circuits into pulses suitable for use in the gated amplifiers and the sensing circuits. As a result of this conversion, the output signal pulses are positive-going, roughly rectangular, and relatively free from noise.

The output pulses from each shaping circuit are fed to a pair of gated amplifiers and also to the sensing circuits in the opposite channel. These circuits give directional sense to the signal pulses so that the outputs of the sensing circuits are the error signals for the torque motors and the control system. In order to understand the operation of these circuits and the method by which directional sense is obtained, it is first necessary to consider the development and characteristics of the signals from the bolometer and commutator.

The presence and spacing of the signal pulses from the bolometer flakes are determined by the position of the target image circle with respect to the bolometer arms. When the image circle is centered on the arms, there will be an output pulse from each flake; and as the mirror rotates, these pulses will occur at the 90-degree points on the scanning circle, as shown in figure 6–13 (A). When the circle is displaced from the center of the cruciform arms, the image will not intersect all of the flakes; and the output pulses from those affected will occur at different points on the circle. For example, if the target is above the scan axis of the mirror, the image will

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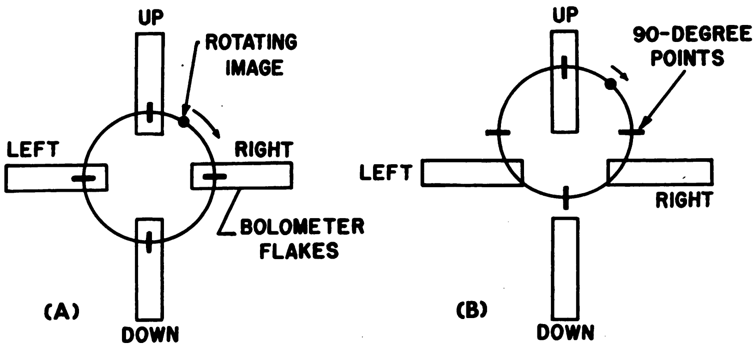

Figure 6–13.—Development of signal pulses.

not strike the DOWN flake, and it will intersect the LEFT and RIGHT flakes at points lying in the lower 90-degree sectors of the circle, as shown in (B) of the figure.

The commutator consists of four sections, one for each gated amplifier. Its function is to allow the signal pulses to pass through the amplifiers except during the time the image is at the 90-degree points on the circle. Each of the four sections supplies the operating voltage for its corresponding amplifier except for a short period of time during each scanning cycle. The commutator is connected to the mirror shaft so that it synchronizes the cutoff time of each amplifier with the proper 90-degree point on the scanning circle. As a result, when the image circle is centered, the amplifiers will be cut off at the time the image strikes the corresponding flake and no error signals will be developed. When the image circle is not centered however, some of the signal pulses will pass through the gated amplifiers and become error signals. As an example, consider the condition when the target is above the scan axis, as shown in figure 6–13 (B).

The presence of the vertical error is detected when the horizontal pulses pass through the gated amplifiers; however, the direction of this error (whether UP or DOWN) is not known at this point. This is determined by the UP pulse (which did not pass through its gated amplifier) in the sensing circuits. The sensing circuits will be cut off for a period of time equal to 150 degrees of the scanning circle when a pulse is received

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from the opposite channel. Thus the UP pulse will cut off the horizontal sensing circuits for 150 degrees after it occurs. Since the RIGHT pulse occurs about 135 degrees after the UP pulse, it will not pass through the sensing circuit; but since there is no DOWN pulse, the LEFT pulse will pass through and become an UP error signal. When the target is off the scan axis in other directions, the proper error signals are developed in a similar manner.

QUIZ

1. All methods of missile guidance have the characteristic of becoming __________ __________ as the missile moves away from the source of control information.
   a. more accurate
   b. less accurate
   c. very sensitive
   d. less insensitive

2. The best collision, or lead course, occurs when the missile heading maintains a ________ ____________ with the line of sight to the target.
   a. constant angle
   b. navigation ratio
   c. pursuit curve
   d. constant velocity

3. The comparison of the rate of turn of the missile to the rate of turn of the line of sight (rate of change of target bearing) is called the __________ __________.
   a. guidance system
   b. radar factor
   c. navigation ratio
   d. attack angle

4. Active homing guidance usually employs __________ techniques to obtain the guidance information.
   a. radar
   b. command
   c. infrared
   d. semiactive

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5. The amplitude modulation of the reflected echoes of an active missile's conically scanned antenna indicates the ________ of the target.

   a. true speed
   b. size
   c. relative speed
   d. bearing

6. In an air-to-surface missile, the radio altimeter supplies ________ information to keep the missile at a constant altitude.

   a. gyro
   b. azimuth
   c. pitch
   d. speed

7. In an air-to-surface missile the radio altimeter reflected signal is compared with the ________ magnetron frequency.

   a. intermediate
   b. high
   c. low
   d. instantaneous

8. A missile employing semiactive homing guidance, receives ________ ________ from the ________.

   a. c-w emanating; target
   b. guidance transmitted; missile
   c. pulses emanating; missile
   d. radiation reflected; target

9. Semiactive missile accuracy ________ during the final phase of the attack while closing on the target.

   a. increases
   b. remains the same
   c. decreases
   d. increases, then decreases

10. The semiactive missile using c-w operation detects the presence of the target by sensing its

    a. relative speed
    b. true speed
    c. range
    d. bearing

11. The Doppler principle pertains to the apparent change in frequency

    a. amplitude due to relative range
    b. due to the range
    c. due to the relative motion
    d. due to changes in the atmospheric conditions

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12. The Doppler value in cycles per second serves as a measure of
    a. true range
    b. true speed
    c. relative speed
    d. true signal amplitude

13. How does the c-w semiactive missile receiver effectively reduce interference and clutter?
    a. By using a comparatively wide band pass
    b. By using a comparatively narrow band pass
    c. By using a low noise figure
    d. By originating the coding signal in the missile

14. The primary reason for using c-w radar in applications of Doppler methods instead of pulse radar is c-w radar
    a. is more effective in working through interference and clutter
    b. has a greater peak power output
    c. has a greater rest period
    d. is not affected at all by angular tracking

15. The semiactive homing missile is suitable for use in
    a. day-fighter operations only
    b. all-weather operations
    c. night-fighter operations only
    d. patrol aircraft operations only

16. In the usual day-fighter installation, the pilot makes his acquisition of the target by
    a. radar
    b. visual means
    c. ground control vectoring
    d. an audible signal in the headset

17. The semiactive illuminator radar is located in
    a. a wing pod only
    b. the nose of the aircraft only
    c. either a wing pod or the nose of the aircraft
    d. a wing pod and the nose of the aircraft

18. Upon acquisition of the target, the f-m/c-w radar measures
    a. altitude and true airspeed
    b. altitude and closing speed
    c. range and true airspeed
    d. range and closing speed

19. The range interlock unit serves as a method of determining
    a. maximum and minimum launching range
    b. whether missile is locked on the target
    c. if the missile is armed
    d. if a true target exists

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20. The purpose of the radio-frequency section of the missile is to

  a. lock the missile local oscillator on the reference signal
  b. determine the correct illuminator
  c. furnish two independent i-f signals
  d. process both of the incoming illuminator signals from the front antenna

21. Information concerning the azimuth and elevation angles of the target is injected on the reflected energy by the

  a. conical scanning of the front antenna
  b. conical scanning of the rear antenna
  c. antenna being polarized
  d. illuminator of the parent aircraft

22. The target's position in __________ and __________ determines the phase and amplitude of the modulation envelope on the echo signal.

  a. range; relative airspeed
  b. altitude; closing velocity
  c. yaw; pitch
  d. angular aspect; range

23. The purpose of the Doppler signal section is to

  a. derive the correct error signal for the autopilot
  b. get rid of any noise that may be present
  c. accept only those signals in the speed spectrum of the missile
  d. recover the amplitude modulation on the front signals

24. The gating and error-detection section

  a. rejects all closing Dopplers
  b. locks on to a valid target
  c. furnishes the local oscillator (r-f section) a lock signal
  d. depends only on the proper operation of the rear-signal channel

25. The useful output of the comparators will be __________ for use as a steering signal.

  a. a d-c voltage with an a-c voltage superimposed on it
  b. a d-c voltage
  c. an a-c voltage
  d. either an a-c or d-c voltage

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CHAPTER 7

INTRODUCTION TO MISSILE CONTROL SYSTEMS

When applied to guided missiles, the word CONTROL has several meanings. Concerning the airframe, the term refers to a physical object such as a movable wing or to any device used to cause a direct change in missile motion. Concerning missiles in general, CONTROL may mean all the numerous processes involved in reaching a specific destination, including the processes of providing "intelligence" and of maneuvering. The term is also used in reference to the necessary changes and corrections made in the path and attitude of the weapon during flight. The action indicated in the last of these definitions is provided by the missile-borne CONTROL SYSTEM, which steers and stabilizes the weapon in accordance with signals from the guidance system and from space reference instruments.

Most missile control systems belong to the class of devices known as SERVOMECHANISMS, a subgroup within the family of automatic control systems. The basic types of control systems, the fundamental principles of their operation, and representative examples of servomechanism components comprise the subject matter of this chapter. The discussion is general in nature and serves as an introduction to following chapters, which deal with applications of control principles in air-launched missiles and with test equipment associated with missile control systems.

BASIC TYPES OF CONTROL

A control system is a combination of components used to govern a flow of energy; and by means of the system, some property of a load is made to conform to a desired condition. The property under control is usually one of the following:

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the position, the rate of rotation, or the acceleration of the load. The system may be composed of electrical, mechanical, hydraulic, pneumatic, or thermal units or of various combinations of different units. The load device may be any one of an unlimited variety; a missile control surface, the output shaft of an electric motor, and a radar tracking antenna are a few typical examples.

DISCONTINUOUS AND CONTINUOUS CONTROL.—The simplest form of control can be illustrated by the elementary electric circuit shown in (A) of figure 7–1. The circuit contains a source of power; a switch, or controlling device; and an unspecified load. The elements are connected in series; and when the switch is closed, energy flows to the load and performs useful work; when the switch is opened, the energy source is disconnected from the load. Thus, the flow of energy is either zero or a finite value determined by the resistance of the circuit. Operation of this general type is called DISCONTINUOUS CONTROL.

In (B) of figure 7–1, the circuit shown is modified by substitution of a rheostat for the switch; and the circuit now provides CONTINUOUS CONTROL. By displacing the rheostat contact, the circuit resistance is varied continuously over a limited range of values. And the energy expended in the load is then varied or regulated over a corresponding range rather than by intermittent, or on-off, action as in discontinuous control. Both these simple examples represent a

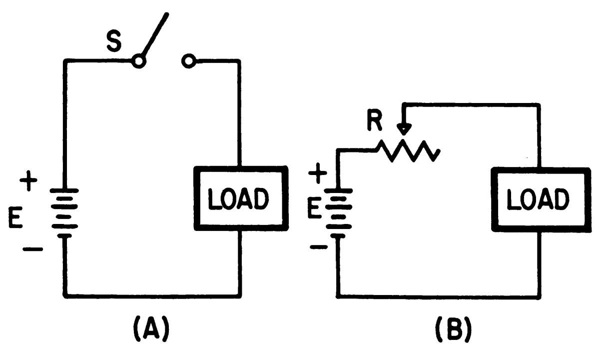

Figure 7–1.—(A) Discontinuous control; (B) continuous control.

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fundamental property of control systems in general: the energy required to control the system is small compared with the quantity of energy delivered to the load.

OPEN- AND CLOSED-LOOP SYSTEMS.—In the examples given above, the power source is controlled directly by manual adjustment of a switch or of a rheostat. In more complicated systems, control signals are applied to the power device by the action of an electrical or mechanical device rather than by manual means. The device which develops the control signals is called an AUTOMATIC CONTROLLER; and the entire system is known as an AUTOMATIC CONTROL SYSTEM.

Automatic control systems can be divided into two basic types: open-loop and closed-loop systems. The essential features of each and the types of components included are indicated by the block diagrams in figure 7–2.

In both systems, an input signal must be applied which represents in some way the desired condition of the load. Assume that the problem is to control the angular position of a shaft attached to the power device, which might be an electric motor. The input signal in this case can be interpreted as the angular position, θ_i, of a control shaft attached to a calibrated dial. The system operation must be such

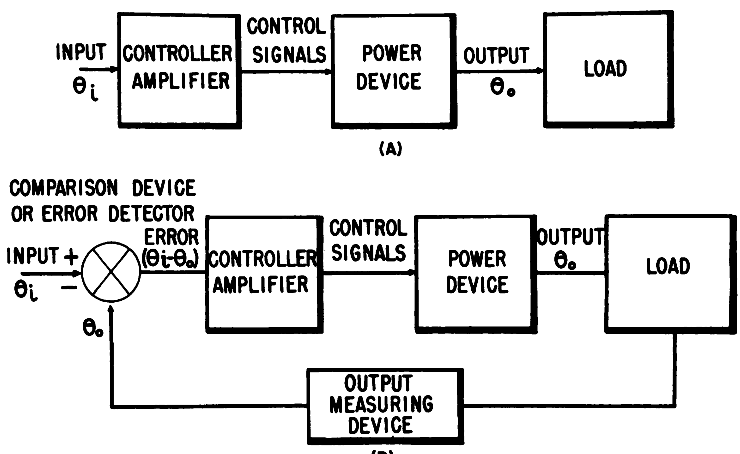

Figure 7–2.—(A) Open-loop system; (B) closed-loop control system.

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that the position of the output shaft θ_o, reproduces the value associated with θ_i, the input.

In the open-loop system shown in (A) of figure 7–2, the input signal is applied to a controller. This section usually contains amplifiers; although its essential function is to convert the input signal into a form suitable for controlling the following stage. The signal from the controller is applied to the power device, which in turn positions the load in accordance with the calibrated input. The characteristic property of open-loop operation is that the action of the system is entirely independent of the result.

The operation of the closed-loop system in (B) of figure 7–2 involves the use of feedback; and the output as well as the input signal determines the action of the power stage. The system contains the same components used in the open-loop arrangement to which several elements are added to provide the feedback function. The output position is measured (either directly or indirectly); and a signal proportional to θ_o is fed back in an appropriate form for comparison with the input value. The comparison is made in a device called an ERROR DETECTOR. The resultant is a new signal, the ERROR, which is proportional to the difference of the input and output. The error signal is applied to the controller, which converts it into a control signal for the power stage. Thus, the system operates in accordance with the error, the discrepancy between the input and output, rather than in accordance with a calibrated input.

For a specific example of closed-loop control, consider the system often used to position the wings of a guided missile. The guidance system supplies an input signal in the form of a voltage, the magnitude and polarity of which indicate the desired position of the wings. The output measuring device (usually a potentiometer) supplies a voltage with magnitude and polarity corresponding to the actual wing position. The two voltages are combined in a circuit which produces an error voltage equal to the difference of the two applied signals. The controller and power stage respond in accordance with the error signal and move the wings until the error value becomes zero, which occurs when the wing

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position is in exact correspondence with the input, or commanded condition.

An example of a typical open-loop system is an automatic washing machine controlled by a timer. The input (the timing mechanism) is set for a certain length of time; and the machine responds by operating in a fixed manner, regardless of the output condition (the degree of cleanliness of the clothes being washed).

Of the two basic types, closed-loop control (also called FEEDBACK CONTROL) is by far the more widely used, particularly in applications where speed and precision of control are required. The superior accuracy of the closed-loop system results from the feedback function which is not present in open-loop systems. The closed-loop device goes into operation automatically to correct any discrepancy between the desired output and the actual load position, responding to random disturbances of the load object as well as to changes in the input signal. Unlike the open-loop system, its accuracy is relatively independent of calibration. And its operation is affected very little by changes in the gain of component amplifiers, by variations of power supply voltage, or by changes of circuit elements due to aging or variations of temperature.

CLOSED-LOOP SYSTEMS

Closed-loop automatic control systems may be classified according to the manner in which the power stage operates in response to control signals. A convenient division is as follows:

1. On-off systems.
2. Step controllers.
3. Servomechanisms.

ON-OFF SYSTEMS are discontinuous in operation. The presence of an error signal causes the power device to be turned on or off; and once the switching process is completed, there is no further control action until the error value changes. A typical example is the operation of an electric refrigerator. Another is the thermostatic control employed

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in some radio transmitters to adjust crystal temperature. In the latter system, when the temperature within the crystal enclosure falls below a certain value, a thermostat is activated and an electric heating element is turned on. When the temperature rises above the critical value, the action of the thermostat removes power from the heater.

In STEP CONTROLLERS, on-off control is modified by including in the system some device which regulates the interval of time during which the power is applied. As the name implies, the desired output is achieved by application of power in steps or pulses. The duration of the pulses is made proportional to the amount of error present; and as a result, the system is less likely to overshoot the desired value than if simple on-off control were used.

SERVOMECHANISMS (or servos for short) are feedback automatic control systems that measure the output, compare it with the input, and use the resulting error signal to control comparatively large amounts of load power in magnitude or in direction or in both. Servos are employed in applications where it is necessary that the output follow rapid changes of the input with accuracy of response and minimum time lag. The true servo differs somewhat from the AUTOMATIC REGULATOR, a type of control in use long before extensive development of servomechanisms took place. In contrast with the servo system, the regulator is designed for response to control signals which change relatively slowly and for maintaining the condition of the load constant despite random disturbances. Typical servo applications include steering of ships, control of missiles and aircraft, automatic tuning of electronic equipment, and numerous uses in telemetering and computing devices.

A Basic Servo System

The fundamental operations and basic components present in most servos can be illustrated by use of a simple electrical system shown in figure 7–3. The principal components shown include a bridge circuit, a 2-phase electric generator, a motor, and a 2-stage electronic amplifier employing triode tubes. Information concerning bridge circuits, generators,

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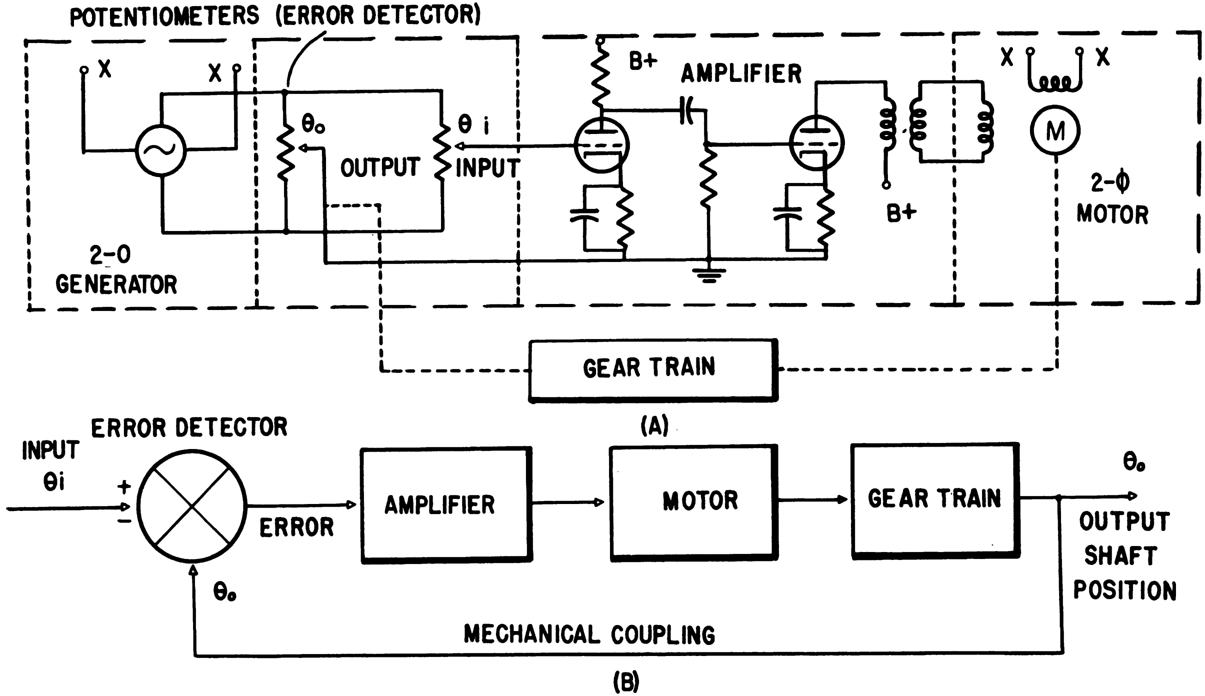

Figure 7-3.—Basic servomechanism. (A) Electrical diagram; (B) block diagram.

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and motors can be found in *Basic Electricity*, NavPers 10086, chapters 5, 14, and 15. The operating principles of triode amplifiers are discussed in *Basic Electronics*, NavPers 10087, chapter 2. The purpose of the system is to adjust the angular position of an output shaft attached to an electric motor. The output shaft is to reproduce accurately the position of an input shaft, which can be given a desired angular setting. Systems of this type, in which the output quantity is an angular displacement, are called POSITION SERVOS to distinguish them from VELOCITY SERVOS, which control the rate of rotation of the output object.

In the servo of figure 7–3, the input shaft position, θ_i, is converted into a proportional voltage by means of a potentiometer; and a similar potentiometer converts the output, θ_o, into a voltage which is used as the feedback quantity. The two potentiometers operate as a bridge; and for each position of the input, there is a corresponding position of the feedback element which will produce zero volts between the two taps.

The bridge output is applied to an electronic amplifier, and the resulting signal is sufficiently powerful to drive one winding of the two-phase motor. The second winding of the motor is supplied with a voltage differing in phase by 90° from the amplifier output signal. Rotation of the motor is transmitted through a series of gears to the output shaft and to the feedback potentiometer.

The potentiometer bridge produces a voltage proportional in amplitude to the lack of correspondence in the input and output shaft positions. The phase of this voltage (representing the relative position or direction of the error) reverses as the feedback potentiometer is driven through the zero position. Hence, the motor may receive zero excitation from the system and remain at rest, or it may be driven in either direction depending on the phase of the error voltage from the potentiometers. The action of the motor is such that rotation tends to reduce the voltage developed by the bridge; that is, it runs until the zero position has been reached indicating that the output shaft conforms to the position of the input. This basic form of operation illustrates a concise

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definition sometimes given of a servomechanism: ". . . an ERROR-CLOSING, closed-loop system."

Oscillation and Damping

A servo system is usually designed to solve a particular control problem and must meet certain performance requirements. Among these are specifications concerning speed of response, accuracy, and the maximum permissible overshooting before the output member comes to rest at the desired condition. A fundamental requirement in every case is stability of operation, or freedom from sustained oscillation by the output device.

One of the methods used by designers to study particular systems is based on the application of test functions, or standard signals, which present the system with extreme performance demands. The response of the system to the input test signal is either calculated or measured directly; and from the resulting data, corrections are made to overcome instability if it is present or to improve system performance if it is required.

A test signal frequently used for this purpose is the STEP FUNCTION illustrated in (A) of figure 7–4. In the case of the electrical servo (fig. 7–3), the step signal can be interpreted as a sudden displacement of the input shaft through the angle θ_i. Some of the possible types of output response are illustrated graphically in (B) of figure 7–4.

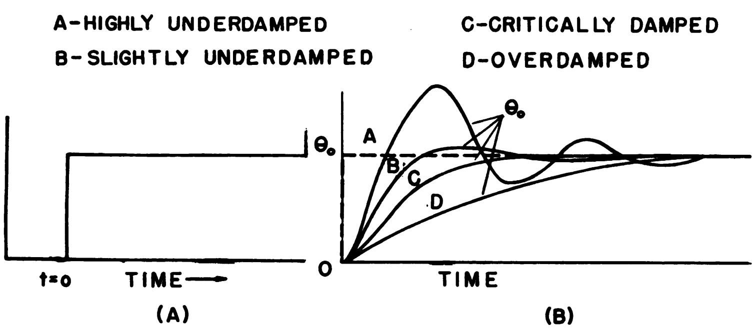

Figure 7–4.—(A) Step displacement function; (B) output response curves.

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If the parameters, or constants, of the systems have been incorrectly chosen, instability may result with the output device oscillating violently about the commanded position. In the electrical control system (fig. 7–3), the parameters of importance are the inertia of the motor and the output shaft, the gain of the servo amplifier, and the amount of friction present in the motor and output section. If the inertia and gain are fairly large quantities and the friction negligible, the response is similar to that indicated in curve A of figure 7–4, in which the output shaft repeatedly overshoots the desired position.

The tendency of the system to develop oscillations (also called HUNTING) is increased if the gain of the amplifier and the inertia are increased. Increasing the friction, however, has the effect of DAMPING the system, decreasing the amplitude of the oscillation and causing them to decay progressively. When there is just enough friction to prevent overshoot, the system is said to be CRITICALLY DAMPED, the condition indicated in curve C of figure 7–4. The OVERDAMPED response occurs when the damping factor is greater than the critical value. In the underdamped condition, small oscillations result as shown in curve B of figure 7–4. Usually, the desirable response is either critical or else slightly underdamped.

Almost all control systems contain components which provide damping or stabilizing action. Among these are VISCOUS DAMPERS. These units artificially increase the load friction, providing a friction component which varies directly with the velocity of the load member. However, this method of stabilization is infrequently employed since the damper consumes a considerable amount of power and also introduces output errors, especially in velocity systems.

In some high-performance control systems, RATE GENERATORS, or TACHOMETERS, are used to provide stabilizing feedback voltages proportional to the time rate of change of the output member. The feedback voltages, when combined with the error signals, introduce damping action without the losses accompanying viscous damping. In electrical servo systems, resistance-capacitance networks are often

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placed in series with the input of the servo amplifier. These combine with the error signal a voltage proportional to its rate of change, and hence, provide ERROR-RATE damping.

In many missile control systems, rate stabilization is based on the output signals from rate gyroscopes and accelerometers, which produce feedback signals used to modify the guidance commands, thereby reducing oscillation and overshoot in the flight path of the weapon.

COMPONENTS OF SERVO SYSTEMS

Servo applications vary widely with regard both to the amounts of power controlled and to the types of components used. However, a basic pattern of essential functions is common to all, with each function carried out by one of the major divisions of the system. The principal component sections, upon which servo operation depends, can be identified in the simple system illustrated in figure 7–3. They are three in number, consisting of (1) the DATA TRANSMISSION SYSTEM, (2) the SERVO CONTROLLER, and (3) the prime mover or power device, which is usually called the SERVOMOTOR.

In the example, the data transmission system contains the potentiometer bridge, or error detector, and the gear train through which the feedback signal is coupled. The servo controller is represented by the two-stage electronic amplifier; and the servomotor section is composed of the two-phase electric generator and motor.

In the following sections of this chapter, representative examples of electrical and mechanical components used in servo data transmission systems and controllers are discussed. Examples of power devices, which in missiles are often hydraulic and pneumatic units, are described in the sections of the text which deal with these general classes of equipment. Coverage of electrical servomotors, including amplidynes, a-c and d-c motors and conventional generators, is given in *Basic Electricity*, NavPers 10086, chapter 17.

Error Detectors

The principal component of the data transmission system is the error detector, the device used for comparing the input

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and output functions. There are two basic types: detectors of position errors, and those which respond to rates of change. An important group of position error detectors operates on magnetic principles and includes the E-transformer, the microsyn and the synchro.

E-TRANSFORMERS AND MICROSYNS.—One form of the E-transformer is illustrated in (A) of figure 7–5. A primary excitation voltage is applied to the coil on the center leg of the laminated E-shaped core. Two secondary coils (B and C in the figure) are wound in series opposition on the outer legs of the structure. The magnetic coupling between the primary and the two secondaries varies with the position of the armature, which can be displaced laterally in either direction.

In the central position of the armature, equal voltages are induced in the secondary coils; and the difference of the two, which is the output voltage of the transformer, is then zero. Displacement of the armature from the central position increases the magnetic reluctance of the air gap near one secondary pole and reduces the secondary voltage. The two voltages are then unequal so that the difference is no longer zero and a resultant error voltage appears at the output terminals. Directional sensitivity is provided since the output voltage changes in phase by 180° as the armature passes through the null point. The amplitude of the output voltage

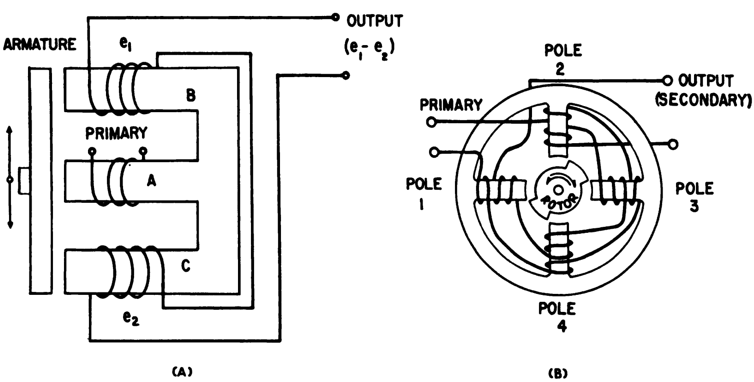

Figure 7–5.—Magnetic error detectors. (A) E-transformer; (B) microsyn.

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is approximately proportional to the displacement of the armature from the central position.

The microsyn, illustrated in (B) of figure 7–5 is an electromagnetic unit containing a two-pole, soft-iron rotor and a four-pole stator. Upon each stator pole is wound both a primary and a secondary coil. The rotor contains no windings and serves only to change the magnetic reluctance in the magnetic paths between the stator poles.

All primary windings are connected in series and the combination is excited with an alternating voltage, usually 400 c. p. s. The resulting magnetic flux tends to flow in two magnetic circuits: between poles 2 and 4, and between poles 1 and 3. The secondary, or output, windings are connected in series in such a way that the voltage induced on one pair of poles opposes that induced on the other. The output voltage is zero when the rotor is in the position shown in the drawing; a displacement of the rotor position causes inequality of the two opposing secondary voltages so that a net output results.

The basic microsyn can be connected to provide a second kind of output, a turning moment, or torque, which is taken from the rotor. The value of the torque is proportional to the product of the currents flowing in the two sets of windings.

SYNCHROS.—The term SYNCHRO is a family name for a group of devices resembling small electric motors and frequently used for transmitting either angular data or torques of fairly small magnitudes. Basically, a synchro is a rotary inductor arranged so that the position of one winding or set of windings can be changed relative to another set, thereby providing variable magnetic coupling. In data transmission systems containing synchros, the basic units usually consist of a synchro generator, either a synchro motor or synchro transformer, and the necessary interconnections.

The fundamental types of synchro units and their applications are discussed at length in *Basic Electricity*, NavPers 10086, chapter 17, to which the reader is referred. The following definitions are given here to serve as a brief collection of basic terms:

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SYNCHRO GENERATOR.—A unit in which the rotor is mechanically driven to generate and transmit electrical signals corresponding to the angular position of the rotor.

SYNCHRO MOTOR (OR RECEIVER).—A unit containing a rotor which is free to turn in response to the electrical signals received from a synchro generator.

SYNCHRO TRANSFORMER.—A unit generally used to provide a single-phase output voltage varying in magnitude with the angle of rotation of its rotor winding with respect to the magnetic field of the stator coils.

SYNCHRO DIFFERENTIAL GENERATOR.—A synchro containing a mechanically driven rotor used for modifying a received signal and transmitting an electrical signal corresponding to the difference of the impressed and modifying signals.

SYNCHRO DIFFERENTIAL MOTOR.—A unit containing a rotor which is free to turn and which is positioned in accordance with the difference of two electrical signals.

SYNCHRO CAPACITOR.—A unit used to counteract the component of lagging current drawn by an inductive synchro device.

MECHANICAL DIFFERENTIALS.—A mechanical differential is often used as an error detector in position servo systems in which the output object is not remotely located from the input station. A differential is a basic mechanism that can either add or subtract. As a detector of position errors, it subtracts the total revolutions of one shaft from those of another and delivers the answer by positioning a third shaft. The product is a very accurate indication; and the device delivers continuous error values as the input and output positions change, either rapidly or slowly.

A bevel-gear differential, the type usually employed in servo applications, is illustrated in (A) of figure 7–6. The heart of the device consists of four bevel gears (shown at the center) together with the SPIDER SHAFT, to which the ERROR GEAR is directly pinned. The two spur gears labeled INPUT and OUTPUT are driven by corresponding elements of the servo system. These gears are free to rotate on bearings mounted on the spider shaft and do not transmit motion to

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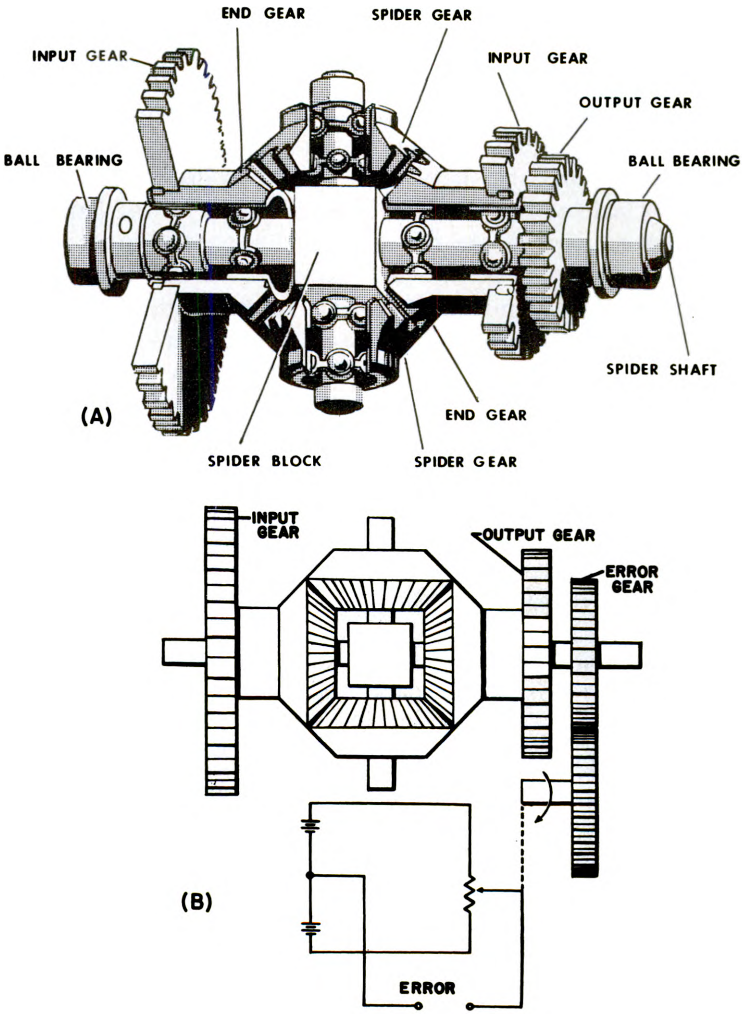

Figure 7–6.—Mechanical differential. (A) Cutaway drawing; (B) schematic.

it directly; instead, they position the two beveled END GEARS. If the output shaft rotates with respect to the input shaft, the spider gears are forced to roll, thus displacing the spider shaft to which the error gear is fixed. The angle

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through which this shaft and gear turn is determined by the difference of the input and output angular positions.

When it is necessary that the error be expressed in electrical terms, the error gear can be made to position one element of a potentiometer bridge, as shown in (B) of figure 7–6. In general applications of the mechanical differential, many functions are possible other than indicating difference values; and any pair of the three spur gears shown in the cutaway drawing can be used as the input and output elements.

VELOCITY-ERROR DETECTORS: TACHOMETER GENERATORS.—When automatic control systems are used to control velocity, the problem is either to duplicate an input rate or to cause the output member to rotate at some velocity proportional to the input signal. In these systems, tachometers are often used as error-detector elements. A TACHOMETER GENERATOR (also called a RATE GENERATOR) is a rotating electromechanical unit designed to produce an output voltage directly proportional to the speed of the rotor shaft. In construction and appearance, typical units are similar to small electric motors and generators. Both d-c and a-c tachometers are used. Units that develop d-c outputs usually contain permanent magnet fields. A-c units are excited by an alternating supply voltage and develop an output with a frequency equal to that of the excitation voltage and a phase or polarity determined by the direction of rotation of the rotor.

Tachometer error detectors contain one or more units connected in various arrangements, a few of which are illustrated in figure 7–7. In (A) of the figure, two d-c units are connected in a circuit called a TACHOMETER BRIDGE. The output voltage of each rate generator is determined by a velocity; and the connection is such that the output of the bridge is the difference of the two corresponding voltages. The polarity of the derived error signal indicates whether the controlled velocity is greater or less than the input value; and the magnitude of the error is proportional to the difference of the two.

The device shown in (B) of figure 7–7 is suitable for use in a velocity control system in which the input is not a velocity but a signal derived from a calibrated potentiometer.

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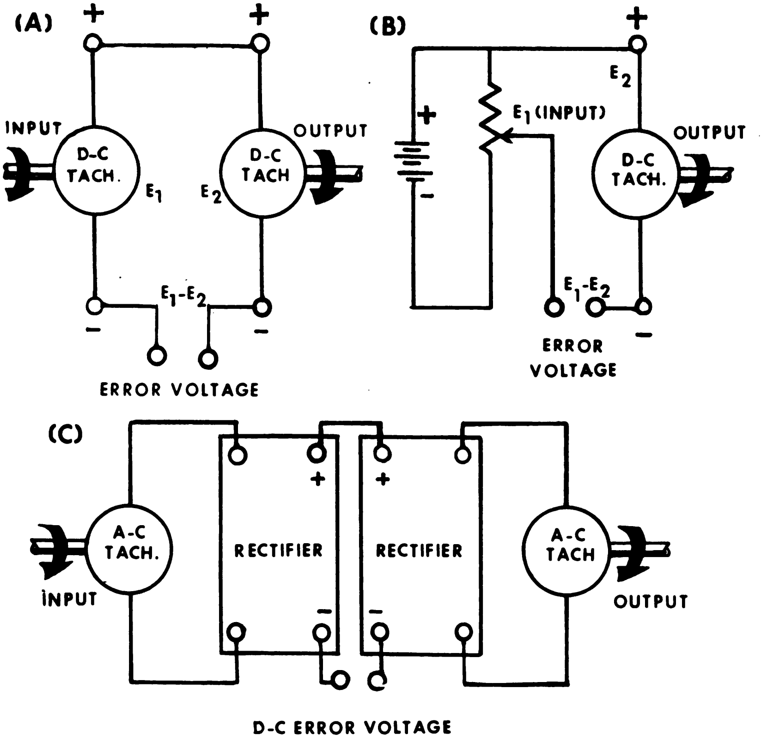

Figure 7–7.—Tachometer error detectors

In (C), an a-c tachometer bridge is shown containing rectifiers which convert the a-c generator outputs into d-c voltages. The rectifiers are employed since the system must indicate the direction of the error; and the phase relation of the two original a-c signals would affect the addition or subtraction of the voltages if these were unrectified. A-c rate generators have the advantage of producing higher voltage per unit speed than typical d-c units. They also require less maintenance and are free from noise produced by commutation.

Airflow-density measurement.—Two devices belonging to a class of velocity instruments entirely different from those previously described are illustrated in basic form in figure

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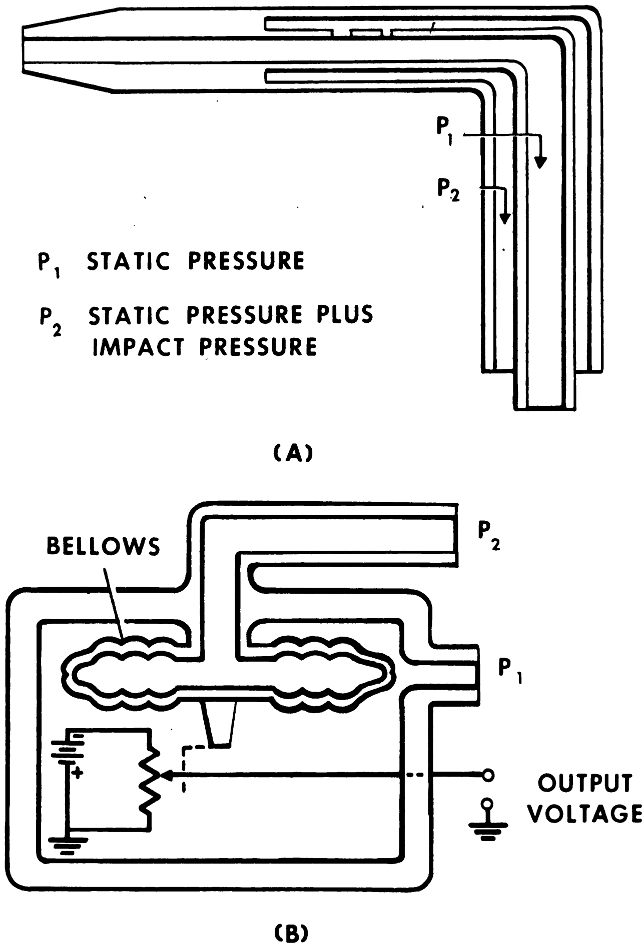

Figure 7–8.—Differential-pressure flow measuring devices.

7–8. The pitot-static tube shown at (A) develops a pressure differential dependent upon the velocity and density of the gas or liquid in which it is immersed. The drawing at (B) is a schematic of a differential-pressure bellows unit, which converts the output of the pitot-static tube into a voltage.

The basic pitot-static unit (PITOT rhymes with VETO) is an assembly containing two tubes bent in an angle. When

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the tip is inserted in a flowing gas or liquid, the inner, or pitot, tube develops a pressure dependent on impact velocity. This pressure (P_2) differs from the pressure in the outer static tube, which contains relatively undisturbed gas or liquid at pressure P_1. Maximum impact pressure results when the circular opening at the tip is perpendicular to the line of flow; and in this condition, the pitot and static pressures are related approximately as in the following equation:

$$P_2 - P_1 = \frac{dV^2}{2g}$$

where d is the density of the gas or liquid,

V is the velocity of flow, and

g is the acceleration of gravity, 32.2 feet per second per second.

Thus, since g is a constant, the difference of the two pressures is determined by velocity and density.

If the pressure P_2 is applied to the inside of the bellows in (B) of figure 7–8; and if P_1 is applied to the outer surface, then the expansion of the diaphragm is a function of the right-hand term in the equation above. In the simple device illustrated, a mechanical linkage converts the bellows position into a potentiometer setting which in turn produces a corresponding d-c voltage.

In missile control systems, instruments of the type shown in figure 7–8 are used principally in gain control circuits, which restrict the response of the weapon to safe values. The lateral acceleration that the missile can stand is limited; and the aerodynamic loading for a given acceleration is a function of missile speed and the density of the surrounding air. The gain control circuit develops a voltage dependent in value upon these factors and applies it as a bias voltage to one of the amplifier stages in the control system. As a result, the response of the control system and the control surfaces is adapted to the conditions of flight and excessive lateral accelerations are avoided.

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The general functions of the servo controller are the following:

1. To supply the necessary amplification of the error signal.
2. To modify the error signal by giving it special characteristics that may be required to obtain stable and accurate operation.
3. To convert the resulting signal into a form suitable for operating the power device, or servomotor.

Every servo controller performs at least one of these functions, and many perform all three. A generalized block diagram showing the necessary components for providing all three functions is shown in figure 7–9.

The input error signal in this system is an a-c voltage, the magnitude and phase of which indicate the amount and direction of the servo error. The first stage of the controller is an a-c amplifier that supplies the gain necessary for proper operation of the following components.

The second component is a phase-sensitive detector, or demodulator. This element transforms the a-c error signal into a d-c voltage with magnitude proportional to the amount of the error, and with a polarity indicating its direction, or sense.

Following the demodulator are one or more electric networks, composed of elements such as resistors and capacitors, or resistors and inductances. Basic types of networks include FILTERS, which are used for attenuating undesired voltages; and EQUALIZING networks, which modify the applied signals to promote stability of operation. PHASE-SHIFTING networks are also employed in some controllers to shift the phase relationship of actuating signals and of supply voltages applied to the component parts.

The final component of the system is a d-c amplifier that raises the d-c signal to a power level adequate for controlling the servomotor.

In many control systems, the controller does not contain

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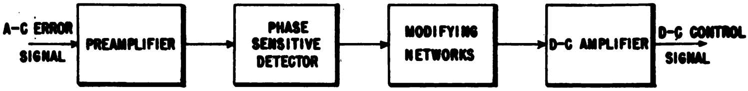

Figure 7–9.—Generalized block diagram of servo controller.

all the components shown in figure 7–9, neither does it necessarily perform all the functions of that system. For example, if the servomotor is to be controlled by an a-c voltage of the same frequency as the a-c error signal, the phase-sensitive detector and d-c network might be eliminated; and an a-c network might be substituted that would produce the required control signal. In general, the controller may be a very simple system, containing only one or two basic units such as amplifiers; or it may be a complex arrangement of electronic, electrical, mechanical, and hydraulic components. In specific applications, the complexity of the controller is determined by the nature of the error signal, the type of power device used, and the performance requirements that the system must meet.

QUIZ

1. An open-loop control system is NOT a/an
   a. positioning system
   b. error-sensitive system
   c. electrical system
   d. mechanical system
2. A closed-loop servo system will operate ONLY when
   a. someone turns a handwheel
   b. a set of contacts is closed
   c. an error exists in the system
   d. the error voltage and reference voltage are in phase
3. In a servo system, an input quantity is compared with an output quantity and the
   a. input quantity controls the load positioning
   b. output quantity controls the load positioning
   c. load positioning is independent of these quantities
   d. difference between the input and output quantities controls the load

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4. The direction of rotation of a positioning servo may be reversed by reversing the phase or polarity of the
   a. error voltage and the reference voltage
   b. error voltage or the reference voltage
   c. d-c plate voltage to the servo amplifier
   d. voltage to the antihunt circuit
5. To prevent overshoot in a servomechanism, without sacrificing accuracy and speed of response, it is a good idea to
   a. apply some additional friction to the output shaft
   b. reduce the gain of the servo amplifier
   c. install a dither device
   d. install an error-rate antihunt device
6. The error voltage supplied to a servo amplifier from a synchro control transformer is
   a. in phase with the reference voltage
   b. out of phase with the reference voltage
   c. an a-c voltage
   d. a d-c voltage
7. A synchro is a
   a. polyphase unit
   b. two-phase unit
   c. single-phase unit
   d. three-phase unit
8. A synchro differential transmitter has two inputs and one output. The inputs are __________ and the output is __________.
   a. mechanical-electrical; electrical
   b. mechanical-mechanical; electrical
   c. electrical; electrical
   d. mechanical; electrical
9. A synchro differential receiver has two inputs and one output. The inputs are __________ and the output is __________.
   a. mechanical-electrical; electrical
   b. mechanical-mechanical; electrical
   c. electrical; electrical
   d. electrical; mechanical
10. The synchro capacitor is used to compensate for lagging, or inductive, currents flowing in the stator circuit(s)
    a. of a synchro transmitter-receiver system
    b. only when differentials are used
    c. only when control transformers are used
    d. of systems using differentials and/or control transformers

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CHAPTER 8

BASIC MISSILE CONTROL EQUIPMENT

This chapter and the chapter following are concerned with basic types of control equipment employed in air-launched missiles: gyroscopes, accelerometers, electronic components, and fluid servo systems composed of hydraulic and pneumatic mechanisms. In the sections of this chapter dealing with electronic circuits, frequent reference is made to subject matter in the basic texts which is required supplementary reading. Most of the related information can be found in chapters 2, 4, 5, and 6 of *Basic Electronics*, NavPers 10087. A section of chapter 5, *Basic Electricity*, NavPers 10086, is also referenced.

Before discussing any particular instrument or electronic component, it is necessary to consider first the overall operation of the entire missile control system; to divide it into convenient groups of units; and to indicate the general function of each major group so that the operation of the particular units may be understood in relation to the operation of the system as a whole.

A GENERALIZED MISSILE CONTROL SYSTEM

The complete system for steering and stabilizing an air-launched missile may be considered as consisting of three major divisions: the guidance system; the missile-borne control units, which function somewhat similarly to an automatic pilot in an aircraft; and the airframe, including the control surfaces, or wings.

Operating together, these groups of equipment function as a large servomechanism made up of several smaller servomechanisms. The input signals required for steering the

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missile are supplied by the guidance system. The controlled output of the total system is the position in space and the motions of the airframe, which functions as the load device of the servo. The control actions accomplished by the control units consist essentially of wing deflections made in response to guidance signals.

The conception of the missile as a servomechanism can be represented by means of a generalized block diagram as in figure 8–1. The figure refers to no particular system but is intended to indicate the basic types of components and control methods usually employed.

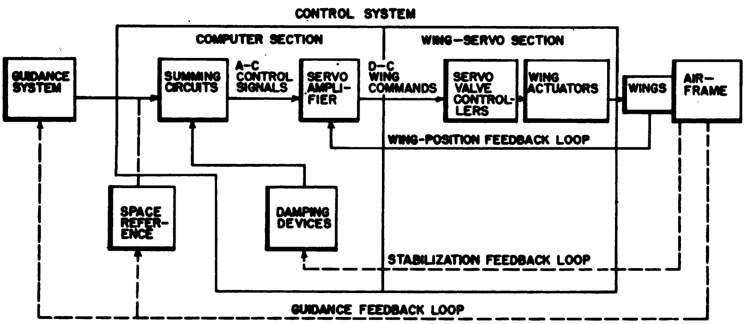

Figure 8–1.—Functional block diagram of generalized missile system.

The units of the GUIDANCE SYSTEM may all be carried in the missile (as in active and passive homing), or they may be distributed between the missile and the launching aircraft (as in beam-rider and semiactive missiles). The principal functions of these units are to detect and track the target; to determine the desired course for the missile; and to produce electrical signals at the input of the control units which (by polarity and amplitude) indicate the position of the missile with respect to the required course.

The position of the missile is determined by relating it to a fixed "frame of reference," or set of coordinates. These consist of one or more lines or points which remain unaffected by the motion of the missile or the launching aircraft. The reference system is either directed toward the target or centered on it and provides the basis for deriving the guidance

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information. In air-launched systems, the required coordinates are established by gyroscopes or by gyroscopically stabilized elements. These, indicated in figure 8–1 by the block labeled SPACE REFERENCE, may be carried in the missile, in the aircraft, or in both.

Control System Components

The units that respond to the guidance signals and actuate the control surfaces make up the major division referred to in figure 8–1 as the CONTROL SYSTEM. These units, which are all enclosed within the missile, may be considered as consisting of two groups: the COMPUTER and the WING-SERVO sections.

Specific computer units vary widely in different missiles because of basic differences in the types of guidance employed; but in most cases, this section contains damping instruments, summing circuits, and servo amplifiers as principal components. In general, these units originate data pertaining to missile motion; sum the data with incoming guidance signals; provide special characteristics in the resulting signals; and produce output voltages suitable for controlling the wing-servo section.

Typical wing-servo sections are composed largely of fluid equipment—of hydraulic and pneumatic units or combinations of both types. This section serves as the power stage of the control system which releases and applies large amounts of energy under accurate control. The principal components of this part of the control system are electrically operated servo-valve controllers; the associated valves; and the hydraulic or pneumatic wing-actuator units which make the necessary adjustments of the control surfaces.

Types of Feedback

As indicated by the feedback loops shown in figure 8–1, the fundamental operation of the guidance and control systems is based on the "error-closing, closed-loop" principle. The control units make corrective adjustments of the missile wings only when an error is present. This occurs when the missile is either displaced from the desired course or when it is

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necessary to counteract forces which would cause it to deviate from the correct heading. In these conditions, the corrective actions taken by the control system are such that any error present is reduced to zero.

THE GUIDANCE FEEDBACK SYSTEM.—Consider first the guidance feedback loop which, as indicated by the broken line (fig. 8–1), is not a physical circuit but rather a method of operation that is "built into" the system. By means of this operation, the position of the airframe as well as the applied guidance signals determine the amplitudes and polarities of the signals which actuate the control units.

In the beam-rider system, for example, steering error voltages are produced in the missile receiver by comparing "fly-up" with "fly-down" guidance puless. A similar comparison is made between "fly-right" and "fly-left" pulses; and when the missile is off course, a net error voltage is produced. The control units make corrective adjustments of the wings in response to the net error signal. As the missile approaches the scan axis of the radar beam (which defines the required course), the error voltage diminishes in amplitude and becomes zero when the missile reaches the correct path.

In the operation of most homing missiles, guidance error signals are produced by detecting the angular positions of the target with respect to the line-of-sight of a gyro-stabilized seeker antenna. As the control system reacts by correcting the missile heading, the error signals progressively decrease and approach zero as the missile comes on course. Thus, in either system, closed-loop, or feedback, action is a fundamental process of guidance and consists essentially of zeroing the error by altering the position of the airframe.

The WING-POSITION FEEDBACK LOOP (fig. 8–1) represents a type of error-closing system employed in the wing-servo sections of most missiles. In typical examples, each wing is mechanically linked to the wiper of a potentiometer, which is adjusted in position as the wing moves. A voltage is picked off that is proportional to the amount of wing deflection and fed back to the corresponding servo amplifier (or similar unit).

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The wing-position voltage is subtracted from the applied control signal to produce an error voltage proportional to the wing correction required to make the actual position match the position required by the control voltage. The action of the wing-servo units is governed by the error voltage, which decreases in amplitude as the wing moves into the desired position.

The STABILIZATION FEEDBACK LOOP (fig. 8–1) indicates in general form the basic method employed in most missile control systems for stabilizing and correcting the flight of the vehicle. The control loop is completed by the inputs and outputs of DAMPING DEVICES, which in most systems are rate gyroscopes and accelerometers. The input to each of these instruments is some motion of the airframe when turning or skidding. The output of each is an electrical voltage proportional to the particular component of motion to which the instrument is sensitive.

The damping voltages are applied to the input of the summing circuits and combined with incoming guidance signals to produce control signals which are corrected for the conditions of motion present in the airframe. The general effects of damping are (1) to oppose any tendency of the missile to deviate from the desired course or heading once it is established, and (2) to prevent or minimize overshooting and oscillation when maneuvering in response to guidance commands.

The effects of rate-damping feedback in preventing overshooting and oscillation are illustrated in figure 8–2. Assume that a beam-rider missile is flying at some distance, x, from the scan axis of the guidance radar. The steering error signal applied to the control units in this condition is a voltage of large amplitude with a polarity corresponding to the error direction. If this signal alone were impressed on the control system, the resulting rate of turning would be greater than the rate of response of the control units, and the missile would approach the scan axis in a path similar to that shown by line (A). With a steep approach angle, momentum causes it to overshoot. Once past the beam axis, the guidance system then impresses a signal of opposite

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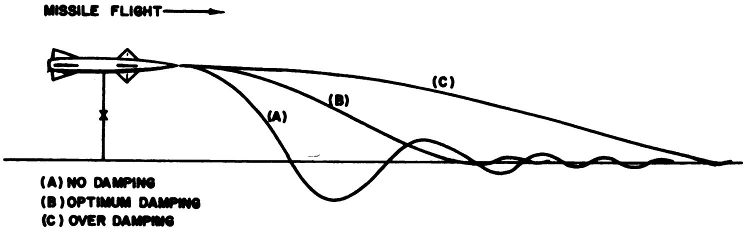

Figure 8–2.—Missile damping action.

polarity, and the overshooting is repeated in the opposite direction. This type of response subjects the airframe to severe stresses and is additionally undesirable since with large error inputs it may result in loss of control.

The damping voltages, when applied to the input of the control system, have the effect of opposing any lateral motion of the airframe. When these are combined with input guidance signals, the rate of turning is reduced and the missile is steered toward the beam axis at a smaller angle of approach.

When the feedback signals are combined with guidance voltages in the proper ratios, the response of the missile is similar to that of any servomechanism with optimum damping, in which there is negligible overshooting and oscillation. This condition is represented by line (*B*) in figure 8–2. Overcorrection, resulting from excessive damping, gives the response shown in (*C*). This condition is undesirable since the action of the missile is sluggish and below the minimum requirements of maneuverability.

The control instruments which provide the damping signals, the instruments which establish the space reference, and the electronic units which combine and process the required electrical information are discussed in the following sections of this chapter. The first two of these deal with gyroscopes and accelerometers; subsequent sections give representative examples of summing and amplifying equipment which convert the electrical data into control signals for use by the wing-servo section.

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GYROSCOPES

Fundamental Properties

In basic form, the gyroscope is a spinning wheel, or rotor, suspended in such a way that the axle is free to rotate about one or both of two axes perpendicular to each other and to the axis of spin. The assembly in which the wheel is mounted usually consists of a rigid support holding one or two pivoted rings or frames called GIMBALS. The innermost gimbal supports the rotor.

The fundamental parts of the gyroscope can be illustrated by the demonstration model shown in figure 8–3. Two gimbal rings are employed which provide UNIVERSAL MOUNTING so that the rotor axle can be alined along any desired direction. The three principal axes about which rotation is possible are: the SPIN axis, defined by the rotor axle; the

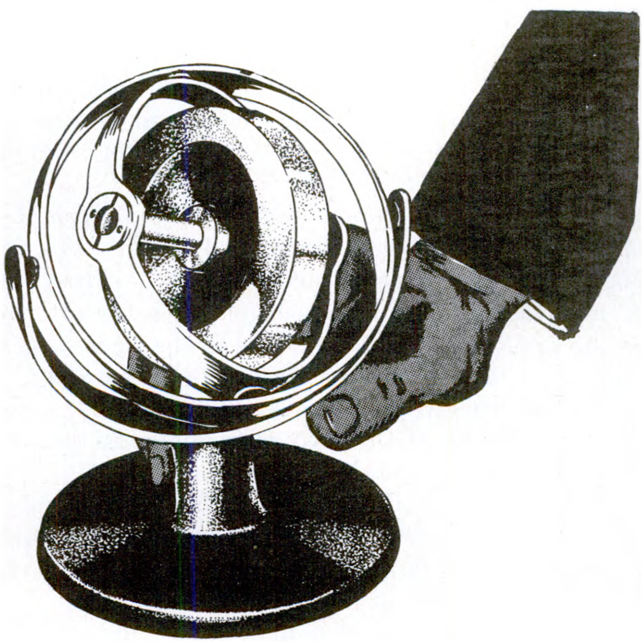

Figure 8–3.—Demonstration gyroscope.

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VERTICAL axis, or the line passing through the bearings of the inner gimbal; and the HORIZONTAL axis, the line passing through the bearings of the support which suspend the outer gimbal ring. The parts of the assembly are balanced; the point of intersection of the axes coincides with the center of gravity of the rotor; and the pull of gravity does not exert torque, or turning force, on the axle.

DEGREES OF FREEDOM.—A gyro with universal mounting, as in the case of the demonstration model, is said to have three degrees of freedom: freedom to spin, to turn, and to tilt. If the outer gimbal ring (fig. 8–3) were removed and the inner ring and rotor mounted in its place, the gyroscope would then have only two degrees of freedom since only one type of rotation would be possible in addition to spin.

GYROSCOPIC PROPERTIES.—Two basic properties of gyroscopes, both of which are of fundamental importance in missile applications, can be illustrated by the use of a simple demonstration model. The first property is RIGIDITY IN SPACE (also called GYROSCOPIC INERTIA, STABILITY, and RIGIDITY IN PLANE), which is the underlying effect employed in missile free gyroscopes. The second property is PRECESSION, the response of the spinning gyro rotor to applied torques.

Rigidity in space is shown in fundamental form by a demonstration gyroscope in figure 8–4. With the rotor spinning, if the gyroscope is picked up by the frame and rotated about any of the three principal axes, the rotor axle retains the same orientation, pointing in the same direction as in the original position. As long as the rotor spins, any torque applied TO THE SUPPORTING FRAME ALONE results only in displacement of the pivoted gimbals and causes no change in the direction of the spin axis.

In missile usage of three-degree-of-freedom gyros, the airframe may be considered as corresponding to the support of the demonstration unit. Rotations about the pitch, yaw, and roll axes are not transferred to the rotor elements which remain unchanged in direction and independent of these motions. Hence, the alinement of the spin axis in such a gyro is space stabilized and is suitable for establishing one

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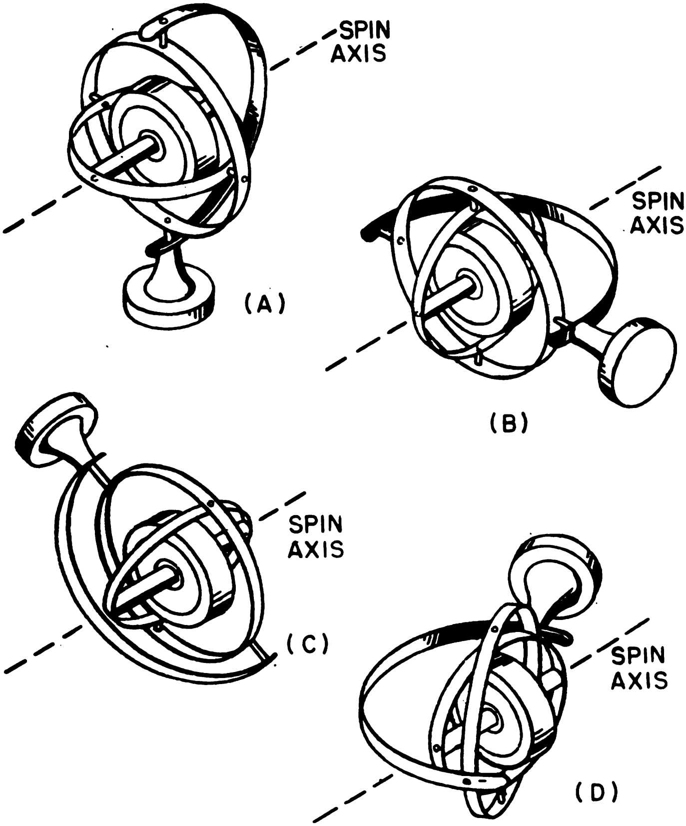

Figure 8–4.—Rigidity in space.

of the coordinates, or reference lines, from which missile headings or target positions can be determined.

Precession, the second of the basic gyro properties, is illustrated in simple form in figures 8–5 and 8–6. It has been shown that rotation of the supporting frame of the demonstration gyroscope has no effect upon the alinement of the rotor axle. If, however, a torque is applied directly to the rotor, by pressing down on the inner gimbal ring, for example, the rotor precesses, or rotates, in the manner shown in figure 8–5.

The drawings show the rotor alone with the gimbals and

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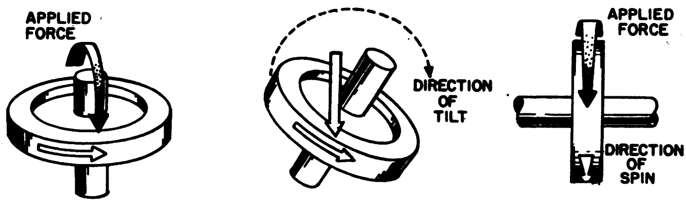

Figure 8–5.—Precession of gyroscope rotor.

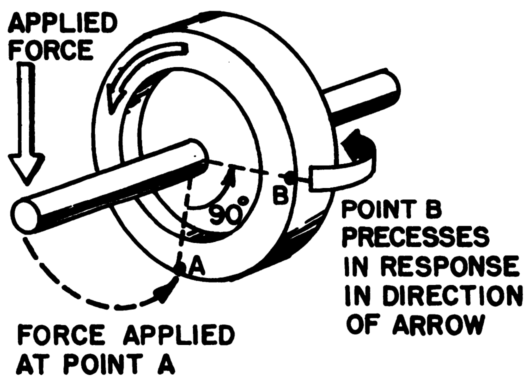

Figure 8–6.—Direction of precession.

frame removed to clarify the action. The applied force exerts a torque which tends to turn the top of the rotor out of the page toward the reader (left-hand drawing). The spinning wheel responds with a motion that is the result of two forces: the applied torque and the force of spin directed along the tangent of the wheel. The rotation, or precession, as shown in the center drawing is such that the top of the rotor moves in the plane of the paper, or a plane removed by 90° from the plane containing the applied force. The final position is shown in the right-hand drawing in which the plane of spin is alined with the plane containing the force. In this position, the precessing torque can no longer act upon the axle and no further precession occurs.

The direction in which the rotor precesses depends upon two factors: the direction of the precessing force, and the direction of spin of the rotor. This is illustrated in figure

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8–6, which also serves as the basis of a simple rule for finding precessional direction. First, determine the direction in which the applied force tends to turn the rotor axle. Next, consider this force as moving in the same plane to a point on the rim of the wheel, such as point A in the drawing. Then imagine that the point is carried 90° around the rim in the DIRECTION OF SPIN, or to a point such as B shown in the figure. The rotor responds as though the precessing force were acting at the latter point rather than at the point of actual application. Thus, the rotor precesses about an axis at right angles to the axis about which the applied force acts.

Missile Gyroscopic Instruments

Missile control instruments based on gyroscopic principles fall into two major classes: free gyroscopes and rate gyroscopes. In the operation of the former, the gyro rotor remains fixed in position, exhibiting the property of rigidity in space, and serving as a fixed element against which motion of the supporting frame can be detected and measured. The rate gyroscope operates by means of precession. In its usual application in missile systems, it is mounted so that rotary motions of the airframe apply torques to the spinning rotor; and the resulting precession serves as a measure of the angular velocity, or rate of turning of the missile about the axis involved.

Instruments of both classes are made up of two kinds of parts—mechanical and electrical. The mechanical elements include gyro rotors, gimbals, and mounting frames. The electrical devices contained in each comprise the PICKOFF, which converts the motion of some part of the gyro into corresponding electrical information.

Many types of pickoffs are used, a few examples being potentiometers, small electric generators, and inductance bridges. The pickoff arrangement in most cases is such that the phase or polarity of the output indicates the direction of the motion sensed by the gyroscope; while the amplitude is proportional to the quantity of motion or displacement.

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Free gyroscopes.—Instruments of the free-gyro type have many applications in missiles. They are employed to stabilize seeker antennas; to establish the space-reference system; to control the action of synchro resolvers, which convert guidance information based on one set of references to corresponding information related to another; and in some cases, to produce guidance signals for steering the missile. The principal elements of most free gyros can be illustrated by an example of an instrument designed for the latter purpose, a mechanical schematic of which is shown in figure 8–7.

The instrument (fig. 8–7) is representative of the type used in beam-rider systems to steer the missile during the thrust phase of flight when it flies a preset course toward the guidance beam. The course is determined by the gyro spin axis, which is alined with the longitudinal axis of the missile when the latter is flying on the correct heading. Any deviation of the missile from this course results in the production of pitch and yaw steering signals by the potentiometers, the two pickoffs. Yaw signals are taken from the upper potentiometer; the left-hand unit provides pitch

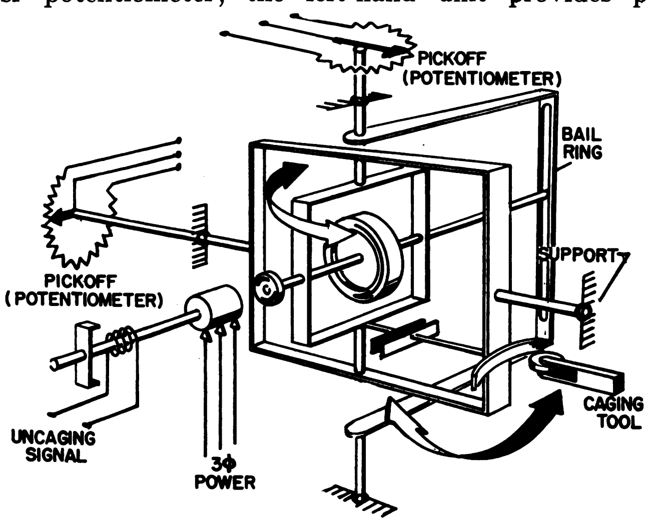

Figure 8–7.—Mechanical schemctic of free gyroscope.

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steering information. The potentiometers are fixed in relation to the missile airframe, while the wiper arms move with the gimbal and bail ring, as shown in the drawing in figure 8–7.

In addition to the gyro assembly and the pickoffs, the parts of essential importance include the driving motor and the means for caging and uncaging the gimbals. The motor which provides driving power is a three-phase, induction motor, the rotor of which surrounds the stator and serves as the wheel of the gyroscope. Electrical energy is supplied to the stator by means of a plug mounted in the housing which mates with a receptacle on the inner gimbal, as shown in figure 8–7.

The rotor is driven at a speed in the order of 40,000 r. p. m. prior to launching and coasts during the brief flight of the missile. Caging, the process of positioning and locking the gimbals, is done in the unit shown (fig. 8–7) by means of a manually operated caging tool. After adjustment, they are locked into position by a pin on the power receptacle. At the time of launching, the gyro is uncaged automatically upon application of an uncaging signal to the solenoid shown in the schematic.

RATE GYROSCOPES.—Like the free gyro, the rate instrument contains a mechanical system consisting of the spinning rotor and associated assembly and also an electrical pickoff for converting the mechanical motions present into electrical outputs. The operation of the instrument can best be understood by considering first the essential mechanical action as shown by a simple demonstration gyro. This unit, illustrated in figure 8–8, has one gimbal ring so that two degrees of rotational freedom are provided—freedom to spin and freedom to tilt, or precess. Further, the rotor is restrained when precessing by the two springs attached to the frame and to the gimbal.

Two axes, the SENSITIVE and the SPRING-RESTRAINED, are shown in the drawing (fig. 8–8). The fundamental operation of the unit involves precession about the spring-restrained axis as a result of rotation about the sensitive axis. This can be described as follows: If the gyro is picked up by

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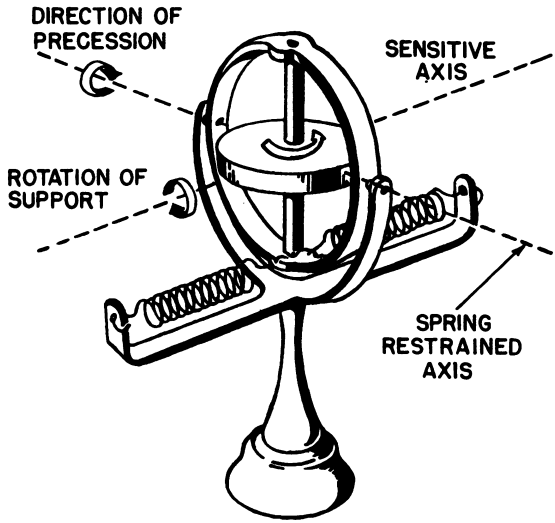

Figure 8–8.—Spring-restrained model gyroscope.

the frame and rotated about the sensitive axis and the direction shown by the curved arrow, a torque is applied to the rotor which tends to tilt it toward the reader. Applying the rule for direction of precession given in a previous section, the point of applied force is carried around the rim of the wheel in the direction of spin, so that the response of the rotor is precession (in the direction of the arrow) about an axis 90° removed; namely, the spring axis.

The tilt, or precession, continues only during the movement of the support. As soon as the latter stops, the spring tension causes the spin axis of the wheel to return to the position it originally had with respect to the support. Thus, there is displacement of the rotor only during actual rotation about the sensitive axis.

If the experiment is repeated several times by rotating the support at different speeds, the following fact will be observed: the higher the speed of rotation, the greater the angle of displacement of the rotor; the lower the rotational speed, the smaller the resulting angle. Further, if the direction of rotation is reversed, the direction in which the

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rotor precesses is reversed correspondingly (which is to be expected from the rule for precessional direction). This simple action illustrates the principle of the rate gyroscope, which can be stated in very simple form as follows: the direction and amount of angular precession of a spring-restrained gyro rotor about the spring axis is a function of the rate and direction of rotation of the support about the sensitive axis and serves as a measure of this rate.

The application of the general principle of rate instruments can be illustrated by means of the mechanical schematic shown in figure 8–9. The gyro rotor is mounted in a cylindrical container which in effect takes the place of the gimbal ring in the demonstration model. From the ends of the cylinder, shafts extend along the spring axis of the instrument (also called the FREE axis) so that the cylinder rotates the shafts when the gyro precesses. One end of the shaft is attached to a pair of restraining springs; the other to the rotor of a signal-generating device, which serves as the pickoff of the instrument.

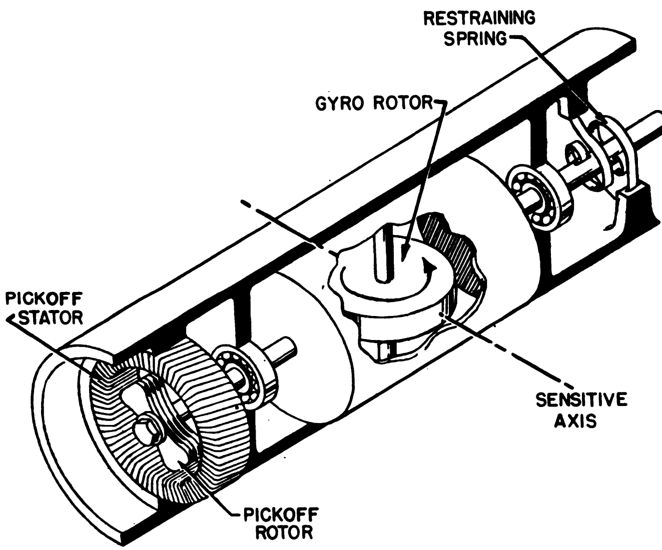

Figure 8–9.—Mechanical schematic of rate gyroscope.

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Stabilizing systems providing rate feedback signals corresponding to turns about each of the principal axes employ three rate instruments of this general type, the sensitive axes of which are parallel to the yaw, pitch, and roll axes, respectively.

The principle of operation of the generator pickoff (fig. 8–9) is illustrated by the drawings in figure 8–10. The stator is made up of ring-shaped laminations and has four poles. On each pole, a primary and secondary coil is wound. The primaries are connected so that with voltage applied, two adjacent poles have the same polarity at any instant. (The primary windings are not shown in the figure.)

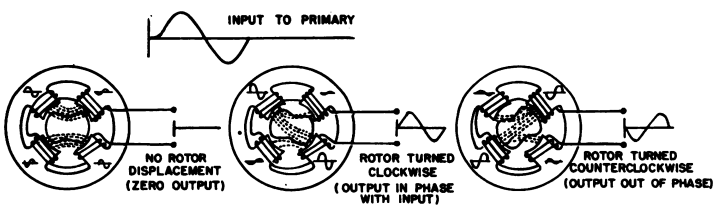

Figure 8–10.—Operation of rate-gyro pickoff.

The secondaries (fig. 8–10) are connected so that in a neutral position of the rotor, the voltages induced in all the coils are equal, and the resultant output is zero. With the rotor turned slightly clockwise, a better magnetic flux path is offered to two opposite poles than to two adjacent poles. The voltages of the opposite poles become greater and those of the adjacent poles become less. Since the opposite poles are of the same polarity, the resultant output will be in phase with the input to the primaries. The magnitude of the output depends, within limits, on the amount of rotor displacement.

Rotation of rotor in the counterclockwise direction (fig. 8–10) produces an output of reverse phase. Thus, the generator pickoff is a device that indicates the direction and amount of rotation of the shaft positioned by the gyro rotor, thereby giving electrical indications of the rates of turning sensed by the instrument.

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ACCELEROMETERS

Accelerometers are essentially mechanical instruments which are designed to measure rates of change of velocity. They are used in missile control systems as damping devices and also in missile telemetering for indicating rates of vibration and oscillation. There are two basic types of these instruments: linear and angular accelerometers. The former type measures straight-line accelerations; the angular accelerometer indicates rates of change of rotational velocity.

In simplest form, the linear accelerometer contains a block of metal possessing considerable mass, the property of bodies which causes them to resist acceleration. The metal block is suspended by springs or on a diaphragm so that it is free to move with respect to the mounting frame along one line called the SENSITIVE AXIS; and hence, is responsive to components of linear acceleration of the frame along this line.

The operation of the linear accelerometer can be understood by means of the schematic diagram shown in figure 8–11. The input to the instrument is the motion of the frame (which, in missile application, is rigidly attached to the airframe). Acceleration along the line defined by the two restraining springs results in corresponding displacements of the metal weight, to which the wiper arm of a

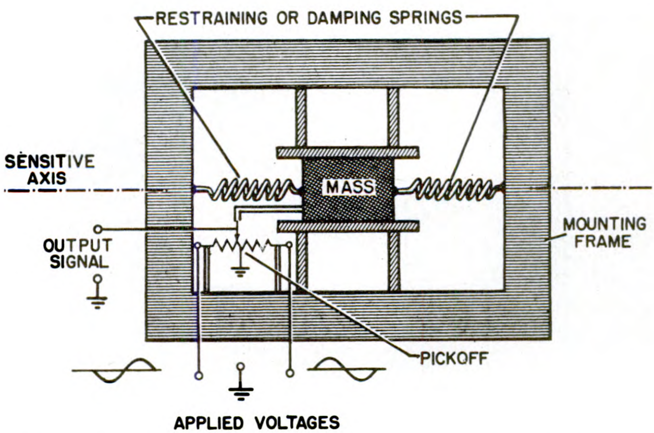

Figure 8–11.—Mechanical schematic of linear accelerometer.

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potentiometer is attached. The output of the potentiometer, the pickoff, is an electrical voltage which indicates by amplitude and phase, the direction and value of the acceleration causing displacement of the weight.

The relation of the sensitive axis of a missile instrument (in this case, a yaw accelerometer) to the principal axes of the missile is shown in figure 8–12. The mounting frame and pickoff are eliminated to indicate clearly the principal action. If the missile receives a guidance signal commanding it to turn right or left, and responds by making a smooth, coordinated turn, there is no output from the accelerometer. If, however, the missile skids or slides sidewise during the turn, the accelerometer weight is displaced away from the center position of the mounting and in a direction opposite to that of the skid.

The output signal produced by the pickoff is fed back for combination with the guidance signal and has the effect of reducing the lateral motion which produced it. Acceleration signals are very effective in damping since they are developed in large amplitude at the beginning of a maneuver and hence have an anticipatory action in minimizing overshooting and oscillation.

The physical appearance of a typical missile accelerometer is shown in (A) of figure 8–13. A schematic diagram in (B)

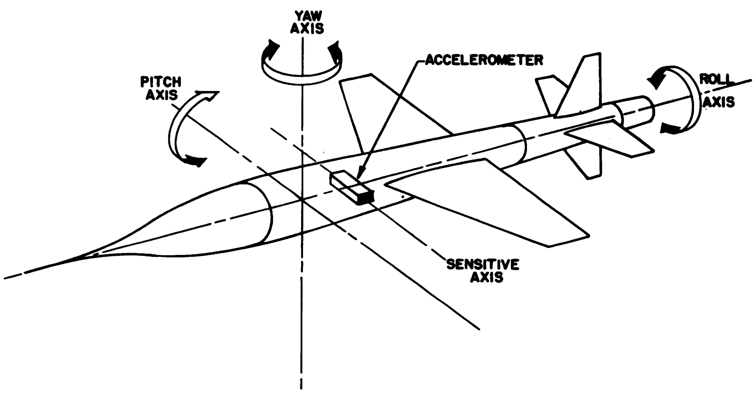

Figure 8–12.—Sensitive axis of accelerometer.

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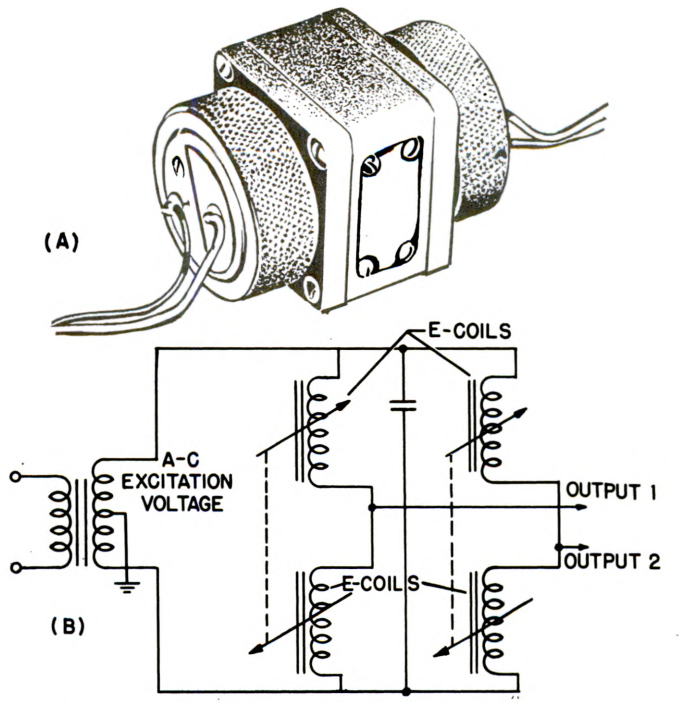

Figure 8–13.—(A) Missile accelerometer; (B) inductance bridge.

illustrates the essential elements of the pickoff circuit, an inductance bridge, which is composed of the output windings of two of these units. Each accelerometer contains a weight suspended by two circular diaphragms. A slug of high-permeability iron, called a MU-METAL PAD, is fastened to each end of the accelerometer mass. The mu-metal pads are separated by a small air gap from the ends of two inductance coils wound on an E-shaped core. When the mass is deflected, the air gap changes, causing the reluctance of the magnetic circuits to change, thereby changing the inductances of the E-coils.

The E-coils of the two accelerometers are connected in parallel with a capacitor to form the bridge circuit shown in (B) of figure 8–13, which is energized by an a-c excitation voltage derived from an oscillator. The capacitor is of a value selected to tune the circuit for maximum impedance.

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The positions of the E-coils are adjusted so that at zero acceleration, the inductance values of the series coils in each branch are equal and the output voltage from each branch is zero. When an acceleration is applied along the axis of one of the instruments, the inductance of one of the series coils increases and that of the associated coil decreases, with the result that the voltage drops across the windings are no longer equal and an a-c voltage proportional to the quantity of acceleration appears at the output.

Angular accelerometers are most frequently employed in missile telemetering applications and are used in some missile control systems to provide feedback voltages proportional to rotational accelerations about the principal axes. In the usual form, the angular accelerometer is composed of a rate gyroscope equipped with some type of device to differentiate the rate signal to give the acceleration value. (To differentitate a signal is to produce another which varies in amplitude with the slope, or rate of change, of the original wave.) In many cases, the differentiation is performed by means of a simple resistance-capacitance combination.

SUMMING CIRCUITS

The summing circuits shown in the functional block diagram (fig. 8–1) produce the control signals for the servo amplifier. These circuits combine the guidance and stabilizing feedback signals in the correct proportions to insure proper response and stability of the missile. The combination of signals is usually accomplished by resistive networks and electronic amplifiers.

Figure 8–14 shows a block diagram of a summing unit of the type employed in beam-rider systems. It contains a LIMITER circuit, SUMMING NETWORK, and AMPLIFIER in each of the three signal channels, and a step RELAY which switches the missile circuits from automatic pilot to beam-rider operation.

During the thrust, or automatic-pilot, phase of missile flight, the pitch and yaw guidance signals are cut off, and signals from accelerometers, free gyros, and rate gyros are combined in the summing networks of the pitch and yaw

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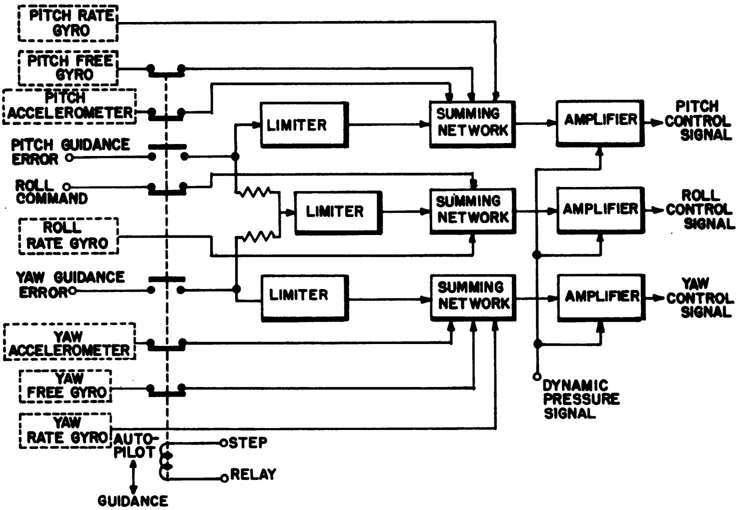

Figure 8–14.—Block diagram of summing unit in beam-rider missile.

channels. In this unit, roll control is provided requiring a roll bias and roll-rate signal to be fed into the summing network of the roll channel. The function of the roll bias is to cause the missile to rotate about the longitudinal axis during the thrust phase of flight, so that any initial misalinement of the wings will result in a helical path about the desired course rather than causing a deviation from the course.

The output signal of each summing network is fed into a two-stage amplifier, the gain of which is controlled by a bias voltage provided by the GAIN CONTROL PRESSURE GAGE situated in the nose section of the missile. The general function of the gain control pressure gage is to modify the control signals in accordance with actual flight conditions of the missile. In most cases, this gage responds to airspeed and to air density and produces a bias voltage which varies in amplitude with these quantities. When applied to the grids of the variable-gain amplifier tubes, the bias then serves to adjust the control-signal voltage so as to insure optimum response of the missile at the particular speed and altitude at which it is flying.

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After the thrust phase of flight, the step relay, actuated by a timer, switches the pitch and yaw guidance signals into the summing unit (fig. 8–14) and the accelerometer, free gyro, and roll bias signals are cut off; and pitch and yaw control signals are applied to the corresponding signal limiters preceding the summing networks. In addition, the pitch and yaw signals are combined in a resistive network so that a summed voltage appears at the input of the roll channel, which causes the missile to roll until it reaches a position in which the signals in the pitch and yaw channels are equal and opposite.

LIMITERS.—The function of the limiters in each of the three channels of the summing unit (fig. 8–14) is to limit the maximum amplitude of the guidance signals in order to prevent the wing deflections from becoming large enough to overstress the airframe when maneuvering.

A limiter circuit of the type employed in the summing amplifier unit is shown in figure 8–15. Two matched triodes, V–1 and V–2, are connected so that each tube clips one peak of any signal voltage which is larger than the desired value.

The first triode operates as a cathode follower with the series combination of R–1 and R–2 as the load resistance. The output is connected directly to the cathode of the second triode, V–2, which operates as a grounded-grid amplifier. The no-signal current through the cathode resistors provides a negative bias for both tubes. If the a-c input signal is

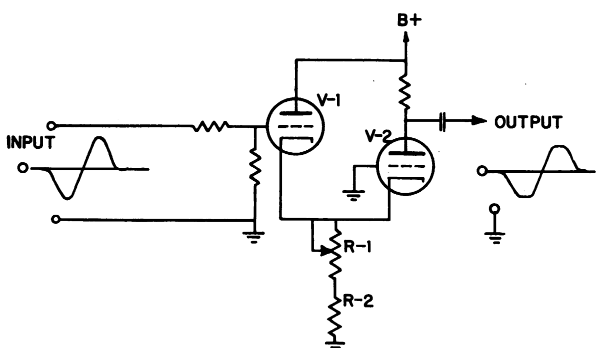

Figure 8–15.—Two-stage limiter circuit.

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larger than the desired maximum, the negative peaks drive the first tube to cutoff so that they are clipped off to the desired value. The positive peaks, which are coupled through to the cathode of the second triode, cause the grid of that tube to become more negative with respect to the cathode, thus driving it below cutoff, with the result that the signal is clipped to the same value as the negative portion of the signal.

(The general operation of the grounded-grid amplifier is discussed in chapter 4, *Basic Electronics*, NavPers 10087; chapter 5 of the same text treats the cathode follower circuit.)

SUMMING NETWORKS AND AMPLIFIERS.—The function of the summing network and amplifiers in each channel of the summing unit (fig. 8–14) is to combine each guidance signal with feedback signals and with the gain-control voltage in the correct proportion for proper operation of the servo system. The combination of signals is accomplished in each channel by a passive resistance network; and the amplification is provided by pentodes of the variable-mu type, the gains of which are adjusted by the bias supplied from the pressure gage.

A basic summing network representative of the type employed in missile summing units is shown in (A) of figure 8–16. The network consists of an input resistor for each signal and a load resistor, all connected in parallel. (This circuit is a special application of the circuit discussed in chapter 5, *Basic Electricity*, under the heading "Parallel Sources Supplying a Common Load.")

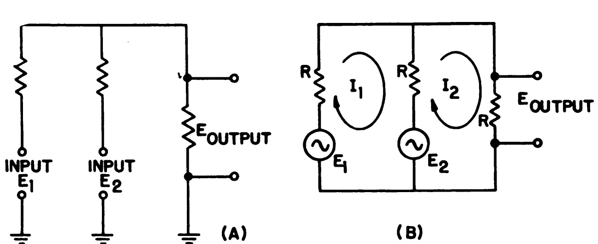

Figure 8–16.—Basic summing network.

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The operation of the summing network (fig. 8–16) can be understood by means of the following analysis. If all three resistors are of the same value, the output voltage is related to the two inputs as follows:

$$E_{\text{output}}=\frac{E_1+E_2}{3}.$$

This equation is derived by applying Kirchhoff's law for the two loop currents indicated in (B) of figure 8–16 in the following manner:

$$E_1=I_1R+I_1R-I_2R+E_2$$

$$E_2=I_2R+I_2R-I_1R.$$

These are simultaneous linear equations, which can be solved for I_2R, the output, in terms of E_1 and E_2, the inputs. Collecting terms gives:

$$E_1=2I_1R-I_2R+E_2$$

$$E_2=-I_1R+2I_2R.$$

Multiplying the second equation through by 2 and adding the two equations:

$$\begin{array}{rrl} E_1= & 2I_1R- & I_2R+E_2 \\ 2E_2= & -2I_1R+ & 4I_2R \\ \hline E_1+2E_2= & & 3I_2R+E_2 \end{array}$$

$$I_2R=\frac{E_1+E_2}{3}=E_{\text{output}}.$$

If signals of opposite polarities are applied as the two inputs shown in figure 8–16, the output will represent the difference of the two. For example, if one input is a 4-volt signal and the other a 1-volt signal, and both are of the same polarity, the output is then a ⅝-volt signal of the same polarity. If these are of opposite polarities, the output is then a ⅓-volt signal with the polarity of the larger.

THE SERVO AMPLIFIER

In this section, a servo amplifier is discussed which is the companion unit to the summing circuits described in the

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preceding section and illustrated in figure 8–14. The control signals developed by the summing unit are modulated waves which provide the information for positioning the wings. The information consists of the amplitude variations present in a carrier wave of fairly low frequency. The phase of the amplitude variations represents the directions of the desired wing adjustments; the amplitude of the variations is proportional to the amount of deflection required.

The servo amplifier accepts the output of the summing circuits; converts the single-ended input signals into push-pull voltages; applies feedback from the wing-position potentiometers; demodulates the modulated waves; and provides d-c output signals suitable for use in the controllers of the wing-servo units.

A block diagram of the servo amplifier is shown in figure 8–17. The unit contains three signal channels to provide pitch, yaw, and roll control. Each channel consists of a PHASE INVERTER, a PUSH-PULL DEMODULATOR, and a push-pull d-c POWER AMPLIFIER. A DITHER OSCILLATOR is included which generates a low-frequency signal for all three channels to cause a continuous vibration of the control valves

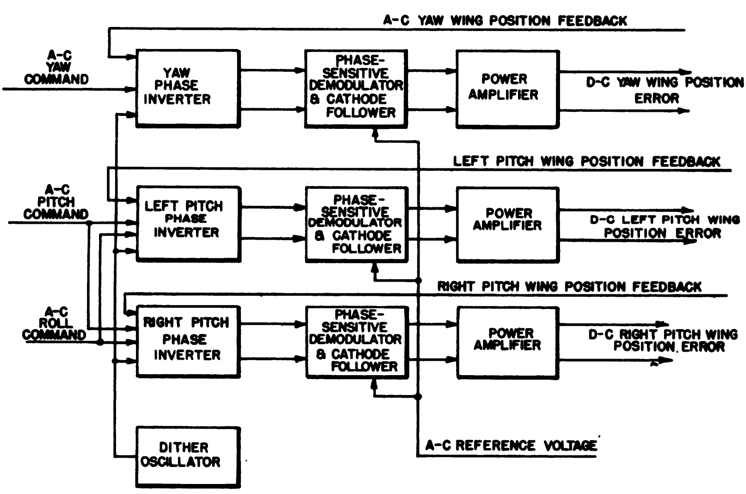

Figure 8–17.—Block diagram of servo amplifier.

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in the wing-actuators in order to eliminate static friction. One channel controls the yaw wing servo in the wing-control section; each of the other two channels controls one of the pitch-roll actuators.

In each channel, the wing-position feedback voltage is subtracted from the wing-command signals in the phase inverter circuits. The result is an a-c error signal which the phase inverter changes into a push-pull signal for the phase-sensitive demodulator. The operation of the phase inverters is similar to that described in chapter 5, *Basic Electronics.*

Phase-sensitive demodulators, or detectors, are frequently employed in servo systems where it is necessary to develop an output voltage which is controlled by two a-c input signals. In these applications, the phase detector does much more than merely demodulate; it provides output d-c voltages which are proportional in amplitude to the amplitude of one of the a-c waves and with polarities determined by the phase relations of the controlling a-c signals.

The phase-sensitive demodulator and associated cathode followers employed in the servo amplifier unit under discussion are shown in figure 8–18. The demodulator is composed principally of four diode tubes, V–1, V–2, V–3, and V–4, each of which is connected in series with a 100K precision

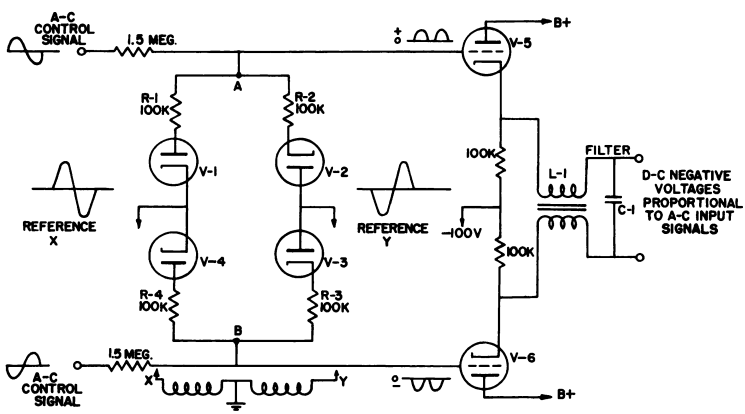

Figure 8–18.—Phase-sensitive demodulator and cathode followers.

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resistor. The two input leads each contain a series resistor of 1.5 megohms.

Two reference voltages, X and Y, are applied to the diode circuit with the result that the diodes are alternately cut off and driven into conduction. When conducting, the diodes and associated resistors form a balanced Wheatstone bridge so that points A and B are placed at ground potential, thereby shorting the grids of the cathode followers, V–5 and V–6 to ground. When nonconducting, the diodes are effectively open circuits. In either case, none of the reference potential is applied to the grids of V–5 and V–6.

The function of the phase detector (fig. 8–18) is indicated by the waveforms shown in the figure. The applied a-c control signals are effectively compared in phase with the reference voltages; rectified by the action of the demodulator diodes; and the resultant applied to the grids of the cathode followers. With control signals of the phase relations shown, the grid of V–5 is driven positive and the grid of V–6 is driven negative. Should the phase relations reverse, the polarities of the pulses applied to the grids would then reverse in accordance.

The rectifying action results from the alternate conduction and nonconduction of the diodes, which are keyed by the reference voltages. When conducting, the demodulator is a balanced bridge which grounds the grids of the triodes. When nonconducting, the diodes resemble open circuits; the triode grids are ungrounded; and the control signals are applied.

The cathode followers (fig. 8–18) serve as coupling devices for applying negative d-c signals to the following stage, a power amplifier. A filter circuit consisting of L–1 and C–1 removes variations from the output so that nonfluctuating potentials appear at the output. The conduction of the triode tubes regulates the negative potential appearing at each output terminal so that the voltage of one relative to that of the other is determined by the phase relations of the input control signals.

THE POWER AMPLIFIER.—The final stage in each of the channels of the servo amplifier (fig. 8–17) is a d-c power

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amplifier. These circuits receive and amplify control signals provided by the cathode followers in the preceding stage and convert the electrical information into mechanical motion of an armature in the corresponding valve controller. The armature, in turn, governs the operation of the wing-actuator units which deflect the missile wings.

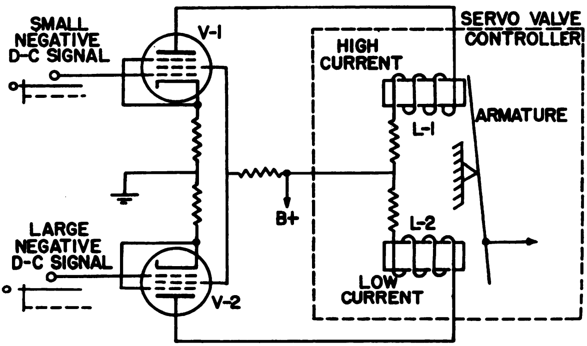

Figure 8–19.—Power amplifier stage of servo unit.

The d-c power amplifier, shown in schematic form in figure 8–19, contains two pentodes, V–1 and V–2, which operate in accordance with the principles of push-pull circuits as explained in chapter 6, *Basic Electronics.* Under control of the applied negative signals, the tubes regulate the currents flowing in the two solenoids, L–1 and L–2. The magnetic fields produced by the solenoids position a pivoted, spring-mounted armature in the servo-valve controller.

The two solenoids act in opposition and are sensitive only to difference currents. When the wing-command signals applied to the grids are equal in amplitude, equal currents flow in the two plate circuits; the magnetic fields are equal; and the valve armature is held in a balanced position so that no change is made in the wing displacement.

When the grid of V–1 becomes less negative than that of V–2, the plate current flowing in L–1 increases and that in L–2 decreases. The resulting magnetic fields are unequal; and the armature is pulled in the direction shown in figure

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8–19. A control signal representing an error of the opposite direction causes the grid of V–1 to become negative with respect to the grid of V–2. The relative currents of the solenoids are reversed and the armature swings away from L–1 so that the servo valve is repositioned and the wings are deflected in the opposite direction.

QUIZ

1. The control system consists of the
   a. guidance system and computer
   b. guidance system and wing servo sections
   c. computer and wing servo sections
   d. wing servo sections and the airframe
2. Typical servo sections are composed largely of
   a. pneumatic systems
   b. hydraulic systems
   c. combinations of pneumatic and hydraulic systems
   d. all of the above
3. The wing position voltage will be greatest when the error voltage is
   a. greatest
   b. smallest
   c. out of phase
   d. in phase
4. Damping devices are used to
   a. establish a space reference
   b. increase rate of correction
   c. minimize overshooting
   d. control acceleration
5. A gyroscope with a mounting frame and two gimbals has
   a. one degree of freedom
   b. two degrees of freedom
   c. three degrees of freedom
   d. four degrees of freedom
6. The three principal axes of a free gyro about which rotation is possible are
   a. vertical, lateral, and horizontal
   b. vertical, lateral, and spin
   c. horizontal, lateral, and spin
   d. vertical, horizontal, and spin

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7. Two basic properties of gyroscopes are
   a. rigidity in plane and gyroscopic inertia
   b. rigidity in space and precession
   c. rigidity in space and stability
   d. stability and gyroscopic inertia
8. If a free gyro, with the rotor spinning, is picked up by the frame and moved about its vertical axis, the rotor axle will
   a. move in the direction of rotation
   b. move in a clockwise direction
   c. move in a counterclockwise direction
   d. remain in the same plane
9. If a force is applied to the side of the rotor of a free gyro, it will precess
   a. directly away from the force
   b. away from the force at a point 90° removed in the direction of rotation
   c. directly toward the force
   d. toward the force at a point 90° removed in the direction of rotation
10. The phase of the output from the pickoff of most gyroscopes is an indication of
    a. amount of movement
    b. direction of movement
    c. rate of movement
    d. amount and direction of movement
11. The amount of yaw movement of a missile is best detected by a/an
    a. free gyro
    b. pitch rate gyro
    c. accelerometer
    d. yaw rate gyro
12. In the form usually employed in missile applications, the rate gyro has
    a. one degree of freedom
    b. two degrees of freedom
    c. three degrees of freedom
    d. four degrees of freedom
13. A spring restrained rate gyro will measure
    a. direction of movement of the missile
    b. amount of movement of the missile
    c. rate of movement of the missile
    d. direction and rate of movement of the missile

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14. Linear accelerometers are usually used in missiles to detect
    a. altitude
    b. yaw movements
    c. skidding movements
    d. pitch movements
15. The air gap between the mu pad and the E-coil of an accelerometer increases. The inductance of that E-coil will
    a. decrease
    b. increase
    c. not vary
    d. double
16. In missile applications summing circuits are used to
    a. detect the guidance signal
    b. detect the stabilizing feedback signal
    c. combine the guidance signal and the stabilizing feedback signal
    d. sum the roll signal with the yaw signal
17. The function of roll bias is to
    a. prevent roll
    b. detect the stabilizing feedback signal
    c. combine the guidance signal and the stabilizing feedback signal
    d. cause roll during the thrust phase
18. The limiters used in the summing circuits are of the
    a. hydraulic type
    b. mechanical type
    c. electronic type
    d. pneumatic type
19. The purpose of the limiters employed in missile summing units is to
    a. prevent excessive wing deflection
    b. prevent overdriving the power amplifier
    c. eliminate roll
    d. limit the roll
20. The amplification of the control signal in the amplifier portion of the summing unit is controlled by the
    a. amplitude of the input signal
    b. bias from the gain control pressure gage
    c. amount of roll rate bias
    d. feedback from the wing potentiometers

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21. Refer to fig. 8–16. If the three resistors each equal 10 ohms, E_1 equals +10 volts, and E_2 equals −40 volts, the output voltage is
    a. −10 volts
    b. −15 volts
    c. −20 volts
    d. −25 volts
22. The output circuit of a typical servo amplifier is a
    a. phase inverter
    b. push-pull demodulator
    c. push-pull d-c power amplifier
    d. dither oscillator
23. The information derived from the phase detector in the servo amplifier controls the
    a. direction the wings deflect
    b. amount the wings deflect
    c. direction and amount the wings deflect
    d. phase of the reference voltage
24. The plate circuits of the power amplifiers described in chapter 8 include the
    a. wing feedback potentiometer
    b. dither oscillator
    c. limiters
    d. valve controller solenoids

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CHAPTER 9

MISSILE HYDRAULIC AND PNEUMATIC SYSTEMS

All missiles must carry sources of primary energy and also mechanisms that convert this energy into large amounts of mechanical output power. In most missiles, these requirements are met by the use of fluid equipment, or devices employing liquids and gases under high pressures. This equipment is of two kinds: hydraulic units, which operate by means of liquids; and pneumatic components that release and control the energy stored in compressed gases, such as air or nitrogen.

Hydraulic and pneumatic systems are employed in several ways in missile applications. They provide the major components of the wing servo system, that section of the total control system that steers the weapon in flight by adjusting the wings, or control surfaces. They also serve as prime movers for electric generators carried in the vehicle. In addition, fluid equipment is required in most missile test sets to supply pressurized gases and liquids for operating the missile-borne equipment during tests and checks made prior to launching.

This chapter is an introduction to the class of equipment employed in these applications. It seeks to acquaint the trainee with basic hydraulic and pneumatic devices and also with the physical principles involved in their operation. This chapter is divided into three sections. The first is a consideration of typical wing servo equipment to give the reader an overall view of the hydraulic and pneumatic equipment contained in typical missile control systems. This is followed by a section dealing with hydraulics—with the primary laws and properties of liquids and with standard hydraulic components. When studying this section, the

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trainee will find valuable additional material and a very complete coverage of principles and components in *Basic Hydraulics*, NavPers 16193. The concluding section contains a discussion of the fundamental gas laws and of representative pneumatic mechanisms in which they are applied.

WING SERVO SYSTEMS

The wing servo units provide the "muscles" of the missile control system. They act in response to electrical signals and apply the enormous forces required for positioning the movable wings of the vehicle during supersonic flight. In some missiles, pneumatic power alone is employed for wing control; but in most, both pneumatic and hydraulic systems are carried. In any case, the fluid units involved comprise a servomechanism, or closed-loop system, which is a part of a larger servo, the missile control system considered as a whole. From this point of view, the wing servo loop functions as a servomotor, or output power stage, which supplies the energy for operating the load, the missile control surfaces.

A basic wing servo system which includes both pneumatic and hydraulic components is shown in figure 9–1. The two kinds of devices work in close conjunction, with compressed gas providing the primary energy required and the hydraulic mechanisms making the actual adjustments of the wings.

The hydraulic components (fig. 9–1) operate as an open

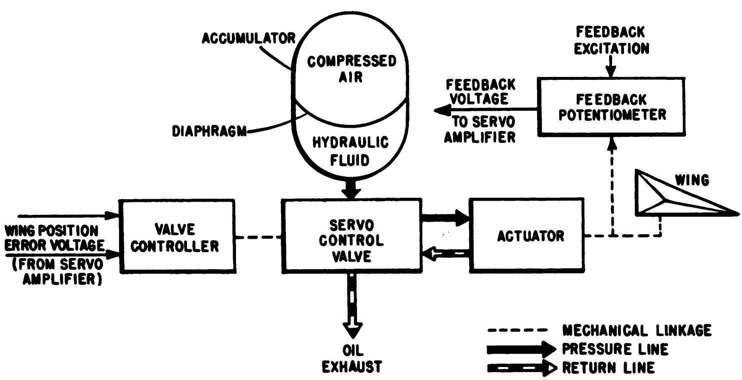

Figure 9–1.—Basic wing servo system.

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system, or one in which the fluid is exhausted to the outside air after passing once through the working parts. The liquid is stored in one section of the ACCUMULATOR. The other section, separated from the fluid by a diaphragm, contains highly compressed air, which forces the liquid first to the SERVO VALVE and from there to the ACTUATOR. Input signals produced by the electronic servo amplifier are applied to the VALVE CONTROLLER, the function of which is to convert the signal voltages into corresponding action within the servo valve. Under control of the valve, the liquid flows into the actuator cylinder and positions a piston within it. The wing is mechanically coupled to the piston and is moved as the piston is displaced.

The feedback potentiometer shown in figure 9–1 is mechanically coupled to the wing and picks off a voltage which represents the actual wing position. This voltage is fed back to the input of the servo amplifier where it is combined with the incoming wing-command signals to produce error voltages. These, through the action of the value controller and servo valve, govern the action of the hydraulic system. The system thus operates as a closed loop device; and the overall action is essentially that of a power amplifier, since a small amount of electrical energy controls a large amount of output hydraulic power.

The maximum time during which the open hydraulic system shown above can operate depends directly upon the liquid storage capacity of the accumulator. The fluid cannot be returned to the pressurized container; and after it is exhausted, the system can no longer function. In missiles designed for longer flights, the wing control sections contain closed hydraulic systems. In these, the fluid is retained, being returned to a reservoir after application to the working parts, and is recirculated by means of one or more pumps.

The pneumatic and hydraulic components typical of closed-system operation are shown in figure 9–2. The associated feedback circuits, valves, and actuators are similar to those illustrated in the open system and are omitted in this drawing. The prime energy source is again com-

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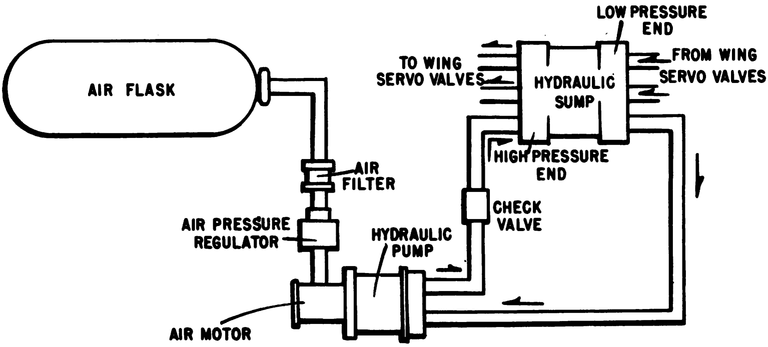

Figure 9–2.—Wing servo system containing hydraulic sump.

pressed air, which is stored in a flask and released at missile launch. Flowing through a FILTER and a PRESSURE REGULATOR, the air enters a pneumatic MOTOR, which in turn, drives a hydraulic PUMP. Impelled by the pump, the liquid flows first to the high-pressure compartment of a two-section reservoir, or SUMP. From there it is distributed to the servo valves and to the wing actuators, from which it is returned to the low-pressure compartment of the sump. There it is held in reserve until taken again by the pump and recirculated at high pressure throughout the system.

The components illustrated in figures 9–1 and 9–2, together with certain fundamentals of fluid mechanics, form the principal subject matter of the following sections. In addition, various elements and parts not shown in the simplified drawings are considered. These include hydraulic fluids, tubing, fittings, connectors, gages, and other devices usually employed in hydraulic and pneumatic systems.

MISSILE HYDRAULIC SYSTEMS

Physical Properties of Liquids

The operation of any hydraulic system is carried out in accordance with the fundamental characteristics of liquids. Among these is the property of SHAPELESSNESS, a characteristic common to both liquids and gases. Because of this

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property, liquids and gases comprise the class of substances called FLUIDS, or those which have the ability to flow.

Both liquids and gases take, more or less readily, the shape of any container enclosing them; and unlike solids, neither has definite form. The two kinds of fluids differ however, with regard to the property of VOLUME. Gases can be easily compressed or expanded to any desired volume and completely fill any container into which they are put; while for all practical purposes, the volume of any given sample of liquid is a fixed quantity as long as temperature remains constant. By this is meant that a quantity of liquid, such as a quart, remains a quart regardless of whether it is put into a quart bottle or into a five-gallon drum.

INCOMPRESSIBILITY OF LIQUIDS.—For practical purposes, the chief difference of liquids and gases lies in the degree to which they can be compressed. While it is incorrect to say that liquids are completely incompressible, they are sufficiently so for most practical purposes. For example, a force of 15 pounds applied on a cubic inch of confined water will decrease it in volume by less than 1 part in 20,000; and a force of over 32 tons would be required to compress it approximately 10 percent.

Because of this resistance to compression, together with the property of fluidity, or shapelessness, liquids provide a very useful means of transmitting forces over long distances and around corners. For example, consider a long tube filled with liquid and containing a movable piston at each end. When one of the pistons is moved, the force is applied immediately to the other piston, regardless of the number of bends in the tube. And the motion of the second piston is as smooth or as rough as that of the first since the impulse is transmitted instantaneously by the liquid.

The near incompressibility of any liquid results in the action illustrated in figure 9–3, in which the response of a confined fluid column to an applied force is contrasted with that of a solid bar. When the end of the bar is struck, the force is carried straight through to the other end since the bar is solid. When the same force is applied to the column of liquid, the shock is transmitted not only along the line of

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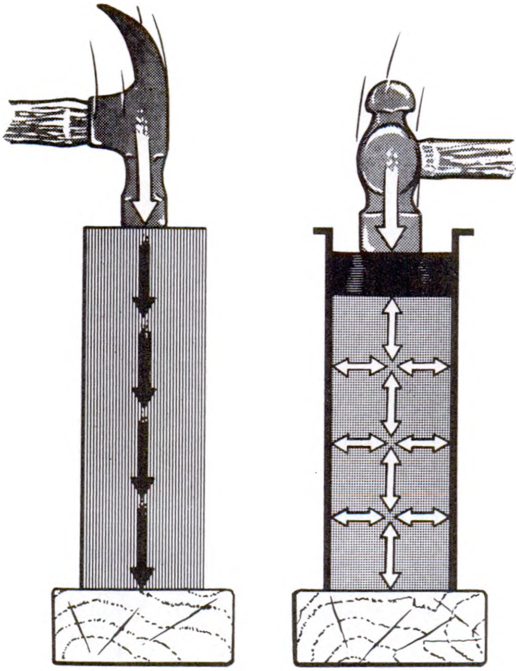

Figure 9–3.—Transmission of force in a solid and in a confined liquid.

the initial thrust; but as indicated by the arrows, it is also applied equally and undiminished in EVERY direction through the liquid—forward, backward, and sideways. As a result, the enclosing vessel is subjected to force at all points.

It is because of the ability of a fluid to transmit force in all directions that flat hoses take on circular cross-sectional areas when water under pressure flows through them. It is also because of the property illustrated in figure 9–3 that depth charges are extremely effective against submarines and do not have to score direct hits in order to crush in the sides. This action of liquids is summed up and expressed concisely by one of the basic principles of hydraulics called Pascal's law; but before considering it, it is desirable that the reader review the meanings of the terms FORCE and LIQUID PRESSURE.

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FORCE AND PRESSURE.—Force is usually defined simply as a push or a pull and is expressed in pounds or in kilograms. The important point with regard to force in the present discussion is that it is completely independent of the area against which it is applied. For example, a 15-pound force is the same regardless of whether it is applied to move a small table across a room or to drive a thumbtack into a bulletin board.

Pressure, on the other hand, is the amount of force applied to each unit of area. It is usually measured in pounds per square inch (p. s. i.) and always designates a ratio of force to surface area. The relation of force to pressure can be expressed by a simple equation:

$$P=\frac{F}{A}$$

where P is the pressure in pounds per square inch, when F is the force in pounds, and A is the area to which the force is applied, measured in square inches.

The same equation can be expressed as

$$F=P\ A,$$

and in this form it might be interpreted in the following way. The total force acting against a hydraulic piston is equal to the pressure of the applied liquid multiplied by the area of the piston.

PASCAL'S LAW OF THE TRANSMISSIBILITY OF PRESSURE.—This principle, which is of basic importance in all hydraulic applications, states that INCREASES IN THE PRESSURE APPLIED TO A CONFINED LIQUID ARE TRANSMITTED EQUALLY THROUGHOUT AND ACT WITH UNDIMINISHED INTENSITY IN ALL DIRECTIONS AND AT RIGHT ANGLES TO THE CONFINING SURFACES. This is a general statement of the fact illustrated in figure 9–3. But it goes further by stating that the pressure increase on a small area of the liquid is conveyed equally to each square inch of the entire enclosing surface, no matter how large the enclosing area may be.

An important consequence of Pascal's law is that an

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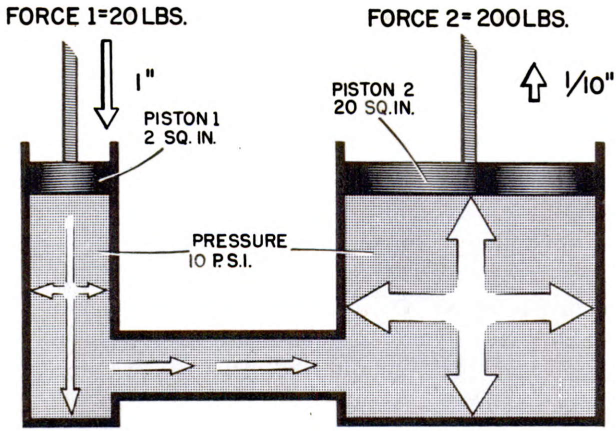

Figure 9–4.—Multiplication of force by hydraulic action.

applied force can be multiplied in value by suitable hydraulic apparatus. This is illustrated in figure 9–4. A force of 20 pounds acts upon piston 1, which has a surface area of 2 square inches. Hence, the applied pressure is 10 p. s. i. According to the law stated above, this pressure acts on all parts of the liquid container, equally and undiminished. Thus, a pressure of 10 p. s. i. is applied uniformly to the lower surface of piston 2, which has an area of 20 square inches. The total force acting against piston 2 is then 10 pounds for each of the 20 square inches, or 200 pounds. In this case, the input force applied to piston 1 is multiplied and appears at the output piston increased tenfold, or in proportion to the areas of the two pistons.

Obviously the system (fig. 9–4) would work the same for other values of applied force, with the ratio of output to input forces remaining ten to one, or the ratio of the areas of the two pistons. The system would also work equally as well in reverse, or if piston 2 were the input and piston 1 the output. In this case, the applied force would be "stepped down," somewhat as the voltage applied to the primary of a filament transformer in a radio causes a voltage of a much smaller value to appear at the secondary terminals.

Note carefully another fact indicated in figure 9–4: while

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the applied force can be multiplied, the WORK cannot. Work is defined as force times distance. Thus, the small piston must move 1 inch downward to lift the large piston $\frac{1}{10}$ inch. Hence, the maximum work done by the latter is 200 pounds times $\frac{1}{10}$ inch, 20 inch-pounds. This is exactly the same work expended by the small piston, which moves 1 inch under a force of 20 pounds.

The multiplication of forces by hydraulic apparatus is comparable to the action of transformers in electric circuits and to the mechanical advantage provided by gears, levers, and the inclined plane in mechanical systems. This principle has many practical applications, a few of which are the hydraulic elevators of aircraft carriers; hydraulic presses; and the familiar barber's chair.

DIFFERENTIAL AREAS.—The dependence of a resultant hydraulic force upon area can be illustrated in a slightly different way by the piston shown in figure 9–5. Hydraulic fluid flows against both faces of the piston so that the pressures on both are equal. The forces developed in each piston face, however, are different because of the difference in the two areas; and a net force is present which moves the piston to the right.

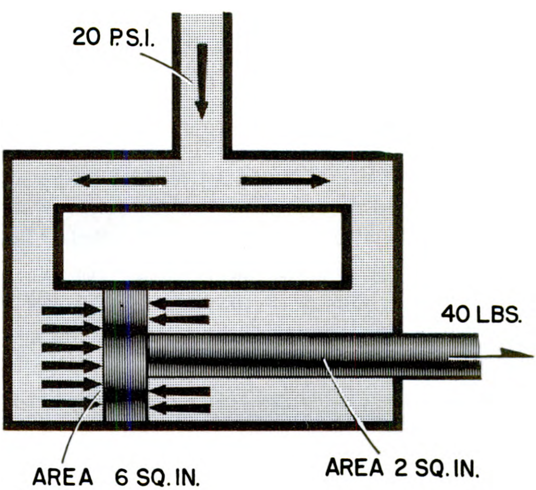

Figure 9–5.—Differential area piston.

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The principle involved in the differential-area piston is employed not only in hydraulic units but also in pneumatic mechanisms, an example of which is an air motor discussed in another part of this chapter.

SUMMARY.—The preceding discussion can be summarized by the following facts concerning liquids which are of practical importance in the operation of hydraulic systems.

1. Liquids are shapeless, completely flexible, and flow readily into enclosures of any form.

2. They are practically incompressible; and applied pressures are transmitted through them instantaneously, equally, and undiminished to all points on the enclosing surfaces.

3. Hydraulic apparatus can be used to increase or decrease input forces, thus providing an action similar to that of mechanical advantage in mechanical systems.

Because of these properties, hydraulic servomechanisms have advantages as well as disadvantages and limitations, when compared with other kinds of systems. The fluidity of hydraulic liquid permits different parts of the hydraulic servo to be placed conveniently and at widely separated points if necessary. The application of pressure is uniform throughout the system and takes place with small losses. Hydraulic power units can transmit energy around corners and bends without the use of complicated gears and levers; and they operate without the slack and friction often present in mechanical linkages. The uniform action is without vibration; and the operation of the system remains largely unaffected by variations in the load value.

An undesirable feature of the hydraulic servo is that one small leak can cause the entire system to fail. Hence, the tubing and other parts must be strong, heavy, and rigid enough to withstand the high pressures required in missile applications. For efficient operation, fluid friction must be kept small; and leaks at joints must be prevented by the use of packing and seals. Dirt and air must be excluded from the system, and corrosion must be kept to a minimum. Pumps and valves must be carefully maintained; and the pressurized equipment introduces an additional safety hazard for personnel repairing and maintaining it.

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The discussion turns now to the basic elements and parts of hydraulic servo systems, the primary one of which is the fluid which serves as the medium for distributing and applying forces.

Hydraulic Fluids

Like any other liquid, standard hydraulic fluids are incompressible, shapeless, and transmit pressures equally in all directions. If these were the only qualities required, any liquid not too thick might be used as a hydraulic fluid. But in addition to the basic properties, a fluid satisfactory for use in a particular system must meet certain specific requirements and must possess a number of desirable properties. The principal ones are as follows: (1) chemical and physical stability, (2) freedom from acidity, (3) lubricating power, (4) proper viscosity, (5) suitable pour point, and (6) suitable flash point.

CHEMICAL STABILITY.—The flúid must be resistant to oxidation and to other chemical changes. If these take place, the result might be the formation of sludge, gums, and carbon deposits, which could cause valves to stick or to leak, openings to become clogged, and the fluid to lose the ability to lubricate. Physically, the liquid should be foam-resistant and should flow readily over a wide range of temperatures.

FREEDOM FROM CORROSIVES.—Not only must the fluid resist chemical changes but it must also be free from corrosive chemicals such as acids. Certain chemicals called ADDITIVES OF INHIBITORS are often dissolved in hydraulic oils to combat corrosion and oxidation. Additives are usually employed in mineral-based fluids in particular, since many of these tend to become corrosive under extreme temperatures and pressures.

LUBRICATING ABILITY.—An essential property of a good hydraulic fluid is the ability to reduce friction in valves, cylinders, pumps, and other units containing moving metal parts. The required action takes place if the liquid, when forced between adjacent surfaces, flows evenly over the areas and forms a thin film on the metal. The film enables the parts to move freely by preventing direct metal-to-metal

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contact. If the film breaks down, the fluid no longer gives adequate lubrication. It is thus desirable that the liquid possess high film strength, or the capacity to cohere and to resist being wiped or squeezed from between the surfaces. Different hydraulic fluids vary widely in lubricating qualities. Also, the lubrication provided by a particular fluid varies with temperature, so that the range of normal operating temperatures of the system must be taken into account when choosing a suitable hydraulic liquid.

VISCOSITY AND VISCOSITY INDEX.—The viscosity of a liquid is a measure of the internal force that opposes flow. When in smooth flow, the liquid can be thought of as being composed of many thin layers, or sheets, which move in relation to each other as well as in relation to the stationary walls of the container. The mutual attractions of the molecules in the layers produce a total force acting in opposition to the force causing the flow; and this total force, which is somewhat similar to friction in mechanical systems, determines the viscosity of the liquid. Thick substances such as tar and molasses have high values of viscosity, while those of liquids such as water and kerosene are much smaller. A satisfactory fluid for a given hydraulic system must have a viscosity sufficiently high to insure good seals in pumps, valves, and pistons. It should not be high enough to result in unnecessary power losses and high operating temperatures. Liquids with very low viscosity values, on the other hand, permit leakage and also lead to excessive wear of moving parts.

The viscosity of a liquid decreases with a rise in temperature. The average spacing of the molecules increases as the temperature goes up; and as a result, the internal attractive forces are lessened, lowering the viscosity. The degree to which this action occurs in a given hydraulic fluid is indicated by a very useful quantity called the VISCOSITY INDEX. This is a number which expresses the change in viscosity with changes in temperature. The higher the index number, the smaller is the viscosity change for a given change in temperature. Systems in which wide variations of temperature take place in normal operation require fluids with high viscosity index numbers. In these, values from 80 to 110 are typical.

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POUR POINT.—The temperature at which a fluid congeals or solidifies when placed in a standard container is known as the POUR POINT. This value varies from fluid to fluid, depending upon the base, the refining methods employed, and the viscosity. Any hydraulic fluid should have a pour point well below the minimum temperature encountered in the operation of the system.

FLASH POINT.—The flash point of a fluid is that temperature at which it gives off vapor in sufficient quantity to ignite momentarily, or to "flash" when a flame is applied. It is desirable that the flash point be as high as possible, consistent with other factors, since a high flash-point value indicates that evaporation is low.

TYPES OF FLUIDS.—Most of the fluids used in naval hydraulic systems have either a mineral base or a hydrolube (water) base. These fluids are usually identified by means of their military specification numbers. Three that are widely used have the following numbers: MIL–O–5606; MIL–H–6083; and MIL–O–7083.

MIL–O–5606 is a fluid with a mineral-oil base. It is the liquid most commonly used in missile hydraulic apparatus. It is red in color and smells like engine oil. This oil has a rated operating range of +160° to −65° F.; it is supplied in red, one-gallon containers; and is flammable under pressure.

MIL–H–6083 has a hydrolube base. It is amber in color and is nonflammable. It may be used in temperatures ranging from +160° down to −60° F. and is supplied in one-gallon containers colored blue and yellow.

MIL–O–7083 is a preservative fluid with a mineral-oil base. It is used for flushing components prior to storage or shipping or when awaiting overhaul or repair. It is red in color and is furnished in red, one-gallon containers.

Tubing, Fittings, and Seals

Hydraulic tubing performs the necessary functions of carrying the fluid from unit to unit and circulating it throughout the system. Fittings are used to connect sections of tubing and also to join them to the various working units. Hydraulic seals, sometimes called PACKING, or GASKETS, have

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a twofold purpose: they prevent loss of pressure in the system, and also keep air out of the lines.

Tubing.—Two types of hydraulic tubing are employed in missile systems: rigid tubes and flexible hose. The former are made of copper, of aluminum alloy, and of stainless steel. Most flexible hose is constructed principally of synthetic rubber. The main requirements of either type are that the tubing or hose have the proper size to permit adequate fluid velocity and that both be physically capable of withstanding the maximum pressures and temperatures present.

The following are typical examples of rigid tubing:

1. Aluminum alloy (52SO), which is suitable for use in systems with operating pressures up to 1,500 pounds per square inch.

2. Aluminum alloy (61ST), a heavier tubing designed for use at pressures up to 3,000 p. s. i.

3. Stainless steel (18–8), a tubing employed in applications in which the lines are subjected to high temperatures.

Flexible hose is used both in missile hydraulic systems and also in missile test equipment. Its primary use is for connecting moving parts and is available in three grades: low-, medium-, and high-pressure. Low-pressure hose is constructed of a seamless, synthetic-rubber inner tubing, upon which is placed a layer of rubber-impregnated fabric and a covering of thin rubber. This type of hose is used only in systems in which the pressure does not exceed 300 p. s. i.

Medium-pressure hose is constructed of a thin, synthetic-rubber hose covered with a fabric braid, a layer of wire braid, and an outer braided fabric cover. This hose is fire-resistant and is used in installations in which the pressure does not exceed 1,500 p. s. i.

High-pressure hose, capable of withstanding pressures up to 3,000 p. s. i., contains a synthetic-rubber inner tube and two layers of braided wire. It is covered with fabric and a layer of thin rubber.

Fittings.—In the general field of hydraulic applications, many kinds of fittings are used. These include flared fittings, flareless tubing; welded connections; screw-type connectors; and quick-disconnect fittings. Of these, AN screw fittings

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and quick-disconnect connectors are of special importance in missile apparatus and in test equipment used in conjunction with missiles.

Two AN screw connectors are illustrated in figure 9–6. The TRIPLE-TYPE, the one most frequently used, contains a sleeve and a nut. The sleeve fits directly over the tubing, the end of which is flared to receive the beveled male connector. The nut fits over the sleeve and, when tightened, draws the sleeve and tubing-flare tightly against the male fitting to make a seal. The sleeve serves to support the tubing so that vibration does not concentrate at the edge of the flare and to distribute stresses evenly over the surface. The STANDARD connector has no sleeve. The inside of the nut fits against the outside of the tubing and clamps it firmly against the male fitting.

AN connectors are made of aluminum alloy and also of steel. Aluminum fittings are blue in color; steel fittings are black.

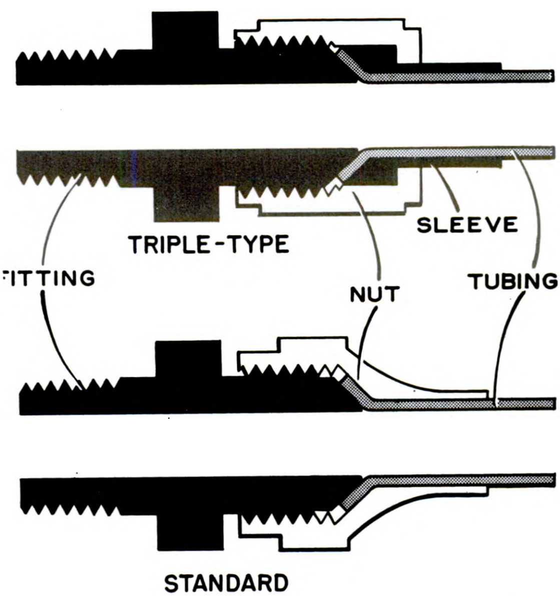

Figure 9–6.—Triple-type and standard tube connectors.

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When connecting screw-type connectors, always thread them together with the fingers. If the thread binds, examine the fittings to make certain that the parts are clean and contain no imperfect threads. Also be sure that mating parts are properly alined to avoid cross threading. Never force a binding thread since additional turning will strip the threads.

When servicing hydraulic systems, it is often necessary to disconnect lines which if opened would permit large quantities of fluid to drain from the system. By the use of QUICK-DISCONNECT fittings, these connections may be made or broken without loss of fluid or the entrance of air. Quick-disconnect fittings are self-sealing couplings. They are used in both hydraulic and pneumatic equipment and are available in many sizes and types. In most cases, the coupling is made in two sections, held together by a coupling nut. Each section contains a spring-loaded valve, which is held open when the coupling is assembled, allowing fluid to flow in either direction. When the connector is disassembled—usually by giving a quarter turn to one of the sections—the valves close and seal the openings to retain the fluid.

These fittings are not designed to withstand the forces resulting from coupling or uncoupling with wrenches. When assembling or disassembling them, use the hand only.

HYDRAULIC SEALS.—Seals, or packings, are required in hydraulic equipment to maintain pressure and to prevent leakage of fluid. Seals are made of comparatively soft materials which are physically strong and chemically resistant to hydraulic fluids. They are placed between mating surfaces both in nonmoving parts, such as fittings, and in units containing moving components. With regard to design, they are made in four general types: O-rings, V-rings (or chevron packing), cup seals, and crush washers. Of these, the most frequently used is the O-ring.

In the installation shown in (A) of figure 9–7, the O-ring is doughnut shaped. The sealing property results from the fact that the ring spreads against the groove containing it when pressure is applied to either side. Hence, it provides effective sealing in both directions. O-rings are made either

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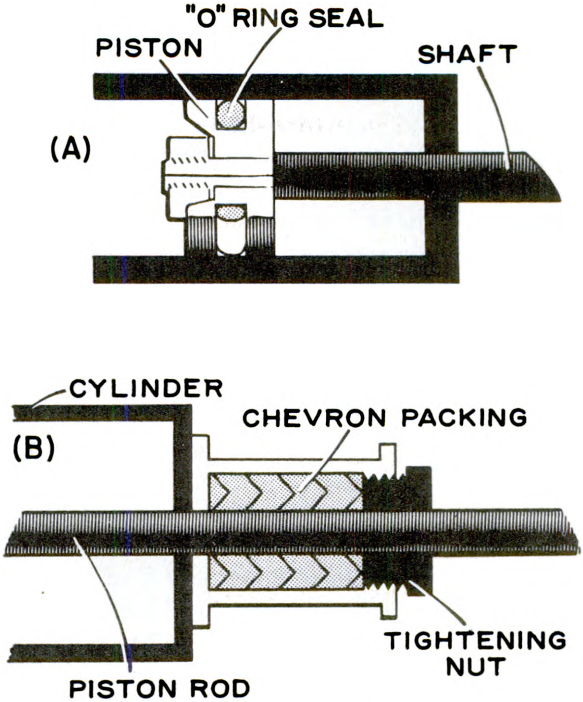

Figure 9–7.—(A) O-ring installed on a piston; (B) V–ring packing.

of natural or of synthetic rubber and are often used in piston heads and valve sleeves.

The V-ring, or chevron packing, is illustrated in (B) of figure 9–7, a cutaway view of a piston-rod assembly. The packing is contained in a FORMER which gives it support and which includes a packing TIGHTENING NUT. CUP SEALS are made of synthetic or of natural rubber and serve to seal against dirt, air, and fluid loss. They are effective for sealing in one direction only. CRUSH WASHERS are metallic seals designed for high-pressure equipment. They are used as air-valve seats on accumulators, on shock struts, and in fittings which screw into various kinds of units. This type of seal is used on nonmoving parts and is generally made of soft aluminum.

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A filter is a screening or straining device used to clean hydraulic fluid and to prevent foreign matter from remaining in the system. The hydraulic fluid holds in suspension tiny metal fragments and other contaminating substances that result from normal wear of the various parts. Unless this material is removed, it can cause damage to the units or even failure of the system. Filters for purifying the fluid are often required in several points—in the high-pressure lines, in return lines, or within the various working units of the system.

MICRONIC FILTERS.—The most effective filter as well as the type used universally in missile apparatus is the micronic, or absorption, unit. These filters are able to remove impurities of exceedingly small dimensions and are thus suitable for use in systems containing working units machined to very close tolerances.

The principal element of the micronic filter is a cylindrical cartridge made of a specially treated cellulose material. The cartridge contains many convolutions, or wrinkles, to in-increase the filtering surfaces; and the filtering action results from the presence of many small openings through which the fluid must pass, during which particles greater than a certain size are removed.

The filtering capacity of a micronic cartridge is measured in microns, a unit of length equal to one-millionth of a meter, or 0.000039 inch. Thus, a filter designed to remove solids greater in diameter than 0.00039 inch is called a 10-MICRON FILTER.

Micronic filters are used in pneumatic lines as well as in hydraulic systems. The purpose in both these applications is the same—to remove particles which might damage the working parts of the system. Two examples of these units are shown in figure 9–8. In (A), the assembly consists of the filtering element, a bypass valve, an in-port, and an out-port. These are all contained within a filter head, a metal enclosure. The fluid enters through the in-port and must flow through the filtering element before discharging through the

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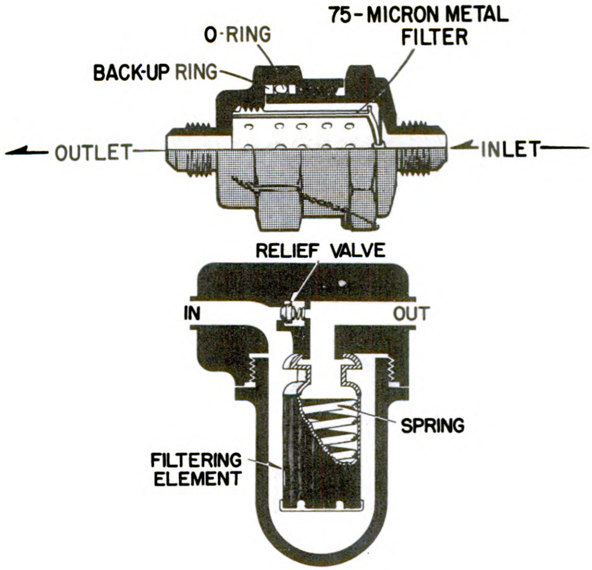

Figure 9–8.—Micronic filters.

out-port. If the filtering element becomes clogged, the by-pass valve opens and permits the fluid to flow directly from the inlet to the out-port.

Although the unit shown in (B) is of slightly different design, the filtering action is similar to that of the previous example. The fluid to be filtered must pass through the cartridge in such a direction that the bulk of the foreign matter is deposited on the outer, or larger area of the element.

No attempt should be made to clean micronic filter elements, since they are designed for use during a limited time only. After the specified operating time, the used element should be discarded and replaced with a new one.

Accumulators.—In closed hydraulic systems, the fluid is stored in a reservoir, which functions both as a starting point and a place of return for the liquid circulating through the lines. In open systems in which the fluid is discarded after passing once through the units, the source of fluid supply is usually a pressurized tank called an accumulator.

A diaphragm accumulator, a type used in many air-

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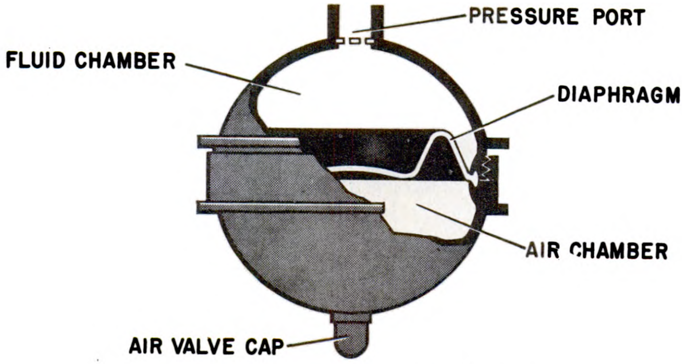

Figure 9–9.—Diaphragm-type accumulator.

launched missiles, is illustrated in figure 9–9. It is made of two hemispherical shells which are bolted together to form a complete sphere. Mounted between the two halves is a synthetic-rubber diaphragm that divides the tank into two chambers, one for compressed air and the other for liquid.

When installed in a missile, the diaphragm accumulator is precharged with air before launching and serves as the source of hydraulic power during missile flight. A valve on the air side of the tank allows the unit to be charged to a high pressure, a typical value being 1,500 p. s. i. During this operation, the diaphragm unfolds and contacts the inner surface of the opposite half of the accumulator.

Fluid is then pumped into the fluid chamber of the unit, further compressing the air up to a value about twice the precharge pressure, or 3,000 p. s. i. In this condition, the accumulator is fully charged and is then able to supply fluid under pressure to the wing actuator units which give motion to the control surfaces of the missile.

BLADDER and PISTON accumulators, together with the diaphragm type illustrated make up the three main kinds of these units. The bladder type consists of a metal cylindrical container enclosing a rubber bladder which is charged with air under pressure. In the piston accumulator, the air and liquid chambers are separated by a movable piston which is free to move from one end of the enclosing cylinder to the

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other. As in the other two types, compressed air provides the energy required to drive the liquid, which is forced from the liquid chamber by the moving piston.

PUMPS.—The hydraulic pump in the closed system shown in figure 9–2 functions as a pressure generator, which receives fluid at low pressure and discharges it at a much higher value. The pump, together with the air motor which drives it, makes up a unit which has the same general function in the closed system as that of the accumulator in the open system shown in figure 9–1. This unit serves to convert the energy stored in compressed air into motion of the hydraulic fluid at high pressure.

Pumps used in closed hydraulic systems are usually of the constant-displacement type, which is characterized by a smooth, nonpulsing output flow. There are three varieties of these pumps: piston, vane, and gear. All are called ROTARY PUMPS, since they are supplied power by means of a rotating shaft. In the closed hydraulic systems employed in some guided weapons and in many missile test sets, the piston-type pumps are most frequently used. These are capable of delivering pressures that range in value from 1,000 to 3,000 p. s. i.

A complete discussion of the various types of hydraulic pumps is beyond the scope of this chapter; and for a complete coverage, the trainee is referred to chapters 8 through 12, *Basic Hydraulics*, NavPers 16193.

General-Purpose Hydraulic Valves

By the use of precision valving devices, designers have been able to develop hydraulic equipment capable of performing intricate sequences of operations and of releasing large amounts of controlled energy. Many kinds of hydraulic valves are available, providing a variety of control functions. Basically, valves govern direction of fluid flow, pressure, volume, or combinations of these quantities. Some are operated by simple manual control; others are controlled automatically by electrical, mechanical, hydraulic, or pneumatic means. In missile systems, the hydraulic valves employed range in complexity from simple check valves to

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complicated servo units. Typical examples of the types important in this field of application are described in the following pages.

CHECK VALVES.—In almost all hydraulic systems, check valves are used for the primary purpose of allowing free flow of the fluid in one direction, while restricting it in the opposite. There are two basic types: bypass and orifice check valves. The former permits free flow in one direction but prohibits it completely in the other; the latter type allows forward flow without hindrance but limits or restricts flow in the reverse direction. In both types, the essential part, or checking device, may be a ball, a cone, or a flapper plate held against a seat by a light spring. The checking device

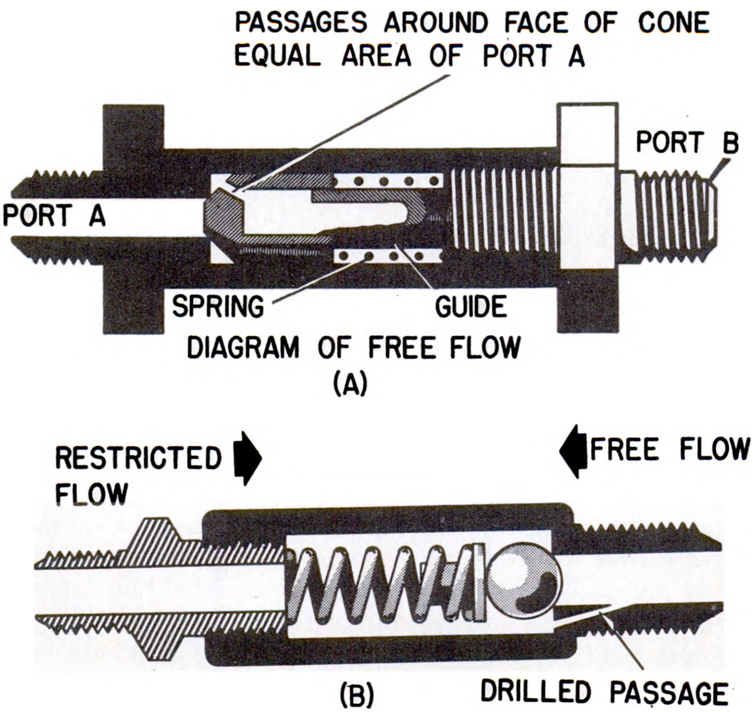

Figure 9–10.—(A) Simple bypass valve; (B) orifice check valve.

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in any case is made to close tolerances and fits tightly against the seat.

A bypass check valve is illustrated in (A) of figure 9–10. The fluid enters port A and unseats the cone, and is thus permitted to emerge at port B. When the flow of fluid in the direction indicated ceases, the spring returns the cone to the seat, thus trapping the fluid that has passed through the unit. A valve of this type might be used to trap and maintain fluid pressure in some particular part of the hydraulic system. The orifice valve shown in (B) of the figure is similar in operation to the bypass unit except that it contains a small hole drilled through the valve seat. When the valve is in the closed position, the orifice allows a small amount of fluid to flow back through in the reverse direction, thereby merely restricting the backward flow rather than cutting it off entirely. When the fluid flows in the forward direction, the action is similar to that of a simple bypass unit of the ball-check type.

RESTRICTORS.—As the name indicates, the purpose of a restrictor in a hydraulic line is to hamper or to slow the rate of flow, limiting it in either direction in the line. In so doing, these valves cause the mechanism that is actuated by the fluid to move slower than it would with unrestricted flow of supply fluid.

Restrictors may be either variable or fixed. One of the former type is shown in figure 9–11. The housing contains two ports for input and outlet of the fluid. The principal element is an adjustable needle valve through which the fluid passes. The size of the passage, and hence, the amount of restriction provided, may be adjusted by screwing the needle valve in or out with respect to the valve seat.

In addition to variable restrictors, fixed or orifice types are also used. These contain a small opening through which the fluid passes in either direction of flow. Unlike the variable unit, the size of the opening cannot be changed so that the restricting action is not subject to adjustment.

RELIEF VALVES.—Relief valves are used in hydraulic systems to protect the equipment from damage which might result from excessive pressures. In construction, a typical

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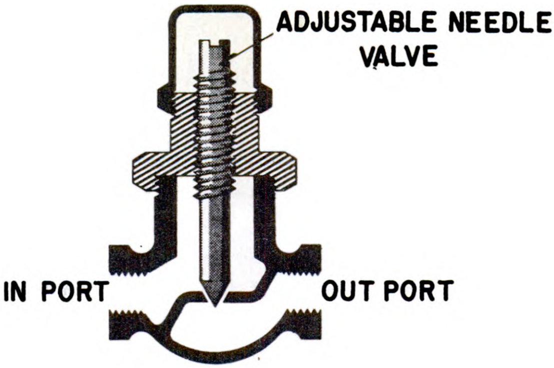

Figure 9–11.—Variable restrictor.

relief valve may resemble a simple check valve except that it is equipped with an adjustable spring which can be set to open the valve when the applied pressure reaches a certain value.

A valve of this kind is shown in figure 9–12. It is controlled by means of an adjustment screw against which the top of the spring is seated. If the pressure reaches the level for which the spring is adjusted, compression results so that the ball valve is opened and the liquid is then bypassed out of the system and back into the reserve supply unit. In

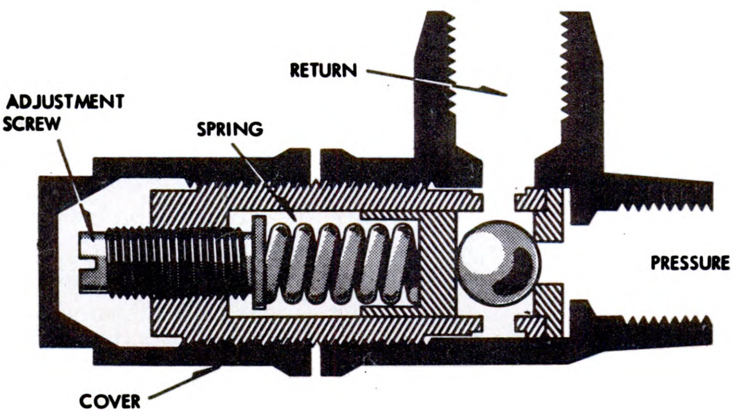

Figure 9–12.—Simple relief valve.

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the unit shown, by turning the adjustment screw inward, the tension of the spring is increased, making it able to resist a higher pressure before opening.

Relief valves are usually installed near the source of pressure so as to protect as much of the entire system as possible. Relief valves designed and used to cause discharge of the entire system are often called SAFETY VALVES.

REDUCING VALVES.—Pressure reducing valves are required when it is necessary to supply a branch line which operates at a lower pressure than that of the main supply line. They are also used when the supply pressure is of a fluctuating rather than a steady value. Most of these valves operate in the following way: fluid at supply pressure acts upon a spring; the spring compresses, permitting a piston to take a balancing position. The piston operates a restricting valve which blocks the flow and lowers the pressure at the outlet to the value determined by the adjustment of the spring.

The operation of a typical reducing valve can be easily understood by study of the schematic diagram in figure 9–13. Liquid enters the valve as indicated by the arrows. It moves past the lower piston into the inner chamber and passes out of the unit. Some of the fluid also rises past the

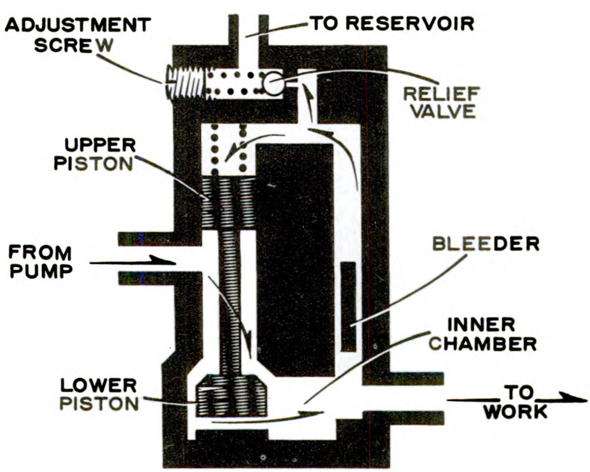

Figure 9–13.—Reducing valve.

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bleeder and enters the upper part of the assembly, where it comes into contact with the upper surface of the main piston and with the relief valve.

The opposed faces of the upper and lower pistons are very nearly equal; hence, the forces acting on them are easily kept in balance by the spring, regardless of the value of the pressure in the high-pressure line. Similarly, a balance is maintained on the low-pressure side: the force acting on the top of the upper piston is balanced by the force on the lower surface of the lower piston. The balance of the low pressures is completely independent of the balance of high pressures.

The low pressure at the output port is determined by the degree of restriction to flow offered by the lower piston. This in turn is determined by the adjustment of the relief valve, an essential part of the unit illustrated (fig. 9–13).

The operation of the relief valve occurs in the following way: When pressure at the output builds up the value for which the relief valve is set to open, some of the liquid is then drained off through it and is returned to the reservoir. Friction losses are large when the fluid passes through the bleeder; and as a result, the loss of a very small amount of fluid causes a large pressure drop in this region of the valve. The pressure drop brings about an unbalance in the forces acting on the upper and lower pistons; and this causes the piston to rise and to restrict the flow still further until the pressure on the discharge side of the valve falls to the value at which the relief valve closes.

The operation of the reducing valve can be summarized in this manner: a simple relief valve, through which a limited flow is permitted, controls a main valve by causing an unbalance of hydraulic forces. The resulting action is such that a balance of forces is restored. The overall result is that the pressure on the discharge side is held practically constant at the value corresponding to the setting of the relief valve.

Directional valves.—The mechanism usually employed to control a unit such as a hydraulic actuator or a fluid motor is a valve designed for governing fluid flow. Valves of this kind are called directional valves and are of two basic

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designs: spool and rotary. Spool valves contain a specially shaped sliding piston which opens and closes passages in the valve block when moved back and forth in the enclosing cylinder. In the rotary design, a round block or core is rotated inside a sleeve; and recesses and passages in the block make the desired connections to conduct the fluid to the controlled unit and to other parts of the hydraulic system. Of these two types, the spool valve is much more frequently used in missile applications.

For discussion of the concepts of directional valves and the details of their construction and operation, consult *Basic Hydraulics*, NavPers 16193, chapter 7. Typical applications of spool valves in missile equipment are illustrated in the section following.

Servo Valves and Controllers

The actuators, or power units of the missile steering system, are controlled by means of servo valves. Each servo valve contains a spool-type directional valve, which directs the flow of high-pressure liquid to a piston in one of the actuators. As a result of the valve action, a difference of forces acts upon the piston, causing it to move in the appropriate direction. Since the piston is mechanically linked to one of the wings, or control surfaces, steering of the missile is accomplished in the particular axis concerned.

The servo spool valves are operated automatically by valve-controllers. These contain solenoid windings which convert the applied wing-command signals into proportional motions of a movable element, or armature. These motions are transferred to the spool valves either through hydraulic circuits or by means of mechanical linkages. The controller equipment and the servo valve components are usually mounted as a single physical unit so that the complete control mechanism for one hydraulic steering channel is contained in a small and compact assembly.

Figure 9–14 shows a typical missile servo valve with associated controller equipment. The servo spool valve is positioned by a hydraulic circuit which, in turn, is operated by a reed flapper valve. The flapper valve is controlled by

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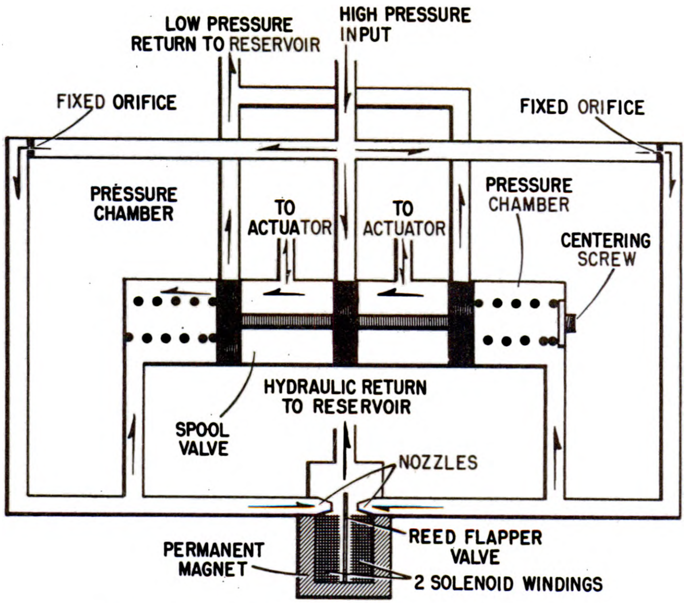

Figure 9–14.—Servo valve with hydraulic control.

a small unit made up of two solenoids and a permanent magnet. The spool valve is free to move in the enclosing cylinder subject to the restraining forces of the centering springs. It moves in one direction or the other when unequal pressures are developed in the two pressure chambers, one of which is located at either end of the spool.

THE HYDRAULIC CONTROL CIRCUIT.—Two high-pressure lines conduct the hydraulic fluid to the pressure chambers. Each line contains a fixed orifice and also a junction leading to one of the nozzles in the flapper valve. The reed in the flapper valve is clamped at one end and extends through the two solenoid windings so that the free end is located between the nozzles. The reed changes in position according to the difference of the currents flowing in the solenoids.

The position of the reed regulates the flow of liquid through the nozzles. For example, as the reed moves toward the right, the flow through the right nozzle is restricted; while the flow through the left nozzle increases.

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The fixed orifices in the unit shown (fig. 9–14) work in a manner somewhat like that of a limiting resistor in an electric circuit: the resistor develops a voltage drop proportional to the value of the current through it. Similarly, the fixed orifices function as restrictions and develop pressure drops proportional to the rate of fluid flow in the lines containing them.

The action of the reed, nozzles, and orifices is as follows. When the reed moves to the right, the flow through the right fixed orifice is restricted so that the pressure drop developed there is reduced. This results in a rise of pressure in the right-hand pressure chamber. At the same time, the flow through the left-hand nozzle increases; the pressure drop at the left fixed orifice increases; and the pressure in the left-hand pressure chamber goes down in value. The two unequal pressures applied at opposite ends of the spool valve cause it to move to the left until the net force is balanced by tension of the centering spring. The motion of the spool valve is reversed when the reed moves toward the left nozzle, since this causes higher pressure in the left-hand pressure chamber than in the right. Hence, the spool valve is centered or moved to right or left depending upon the position of the controller reed.

When in the center, or zero position, the spool valve (fig. 9–14) prevents liquid from entering either of the two lines leading to the actuator. When the spool moves to the left, for example, the center piston admits high-pressure fluid to the right actuator line; while at the same time, the left piston opens the return line to the left side of the actuator. Motion of the spool in the opposite direction results in a reversal of the connections so that the actuator responds in the opposite manner.

SOLENOID CONTROL CIRCUIT.—The solenoids, or electromagnets, in the servo controller operate according to the general principles discussed in chapter 7, *Basic Electricity*, NavPers 10086. In the unit illustrated in figure 9–14, the two solenoids produce opposing magnetic fields that combine with the field of the permanent magnet. The resulting field provides the magnetic force for adjusting the position of the

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controller reed. The polarity of the resultant field, which governs the direction of reed motion, depends upon the amount of current flowing in one of the windings relative to that of the other.

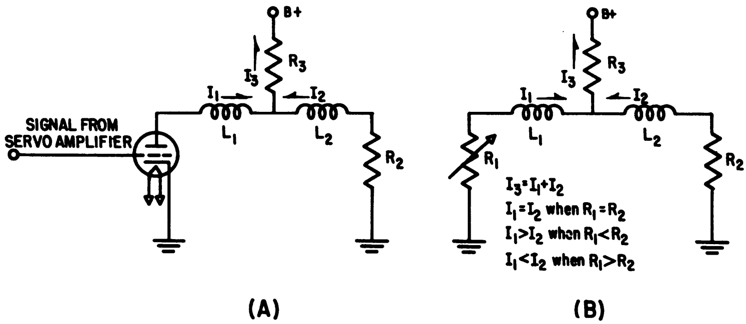

Figure 9–15.—(A) Solenoid control circuit, (B) equivalent circuit.

A simple circuit for controlling the ratio of the solenoid currents is shown in (A) of figure 9–15. The plate circuit of the triode tube functions as a variable resistor in series with one winding, as indicated in the equivalent circuit in (B) of the figure. In the static, or no-signal, condition, the conduction of the tube is such that the currents in both windings are equal. As a result, the reed is centered, and no change occurs in the position of the servo valve. When an error signal is applied to the grid, the current in coil L_1 becomes either greater or less than the current in L_2, depending upon the polarity of the signal. If the signal increases conduction, the magnetic field strength of L_1 is greater than that of L_2, and the resultant magnetic field deflects the reed toward one of the nozzles. Signals which decrease tube conduction cause a reversal of the resultant magnetic field so that the reed is deflected toward the other nozzle.

Mechanical valve controllers.—Another type of servo valve often used in missile hydraulic systems is shown schematically in figure 9–16. The solenoid circuit is of the type described above. It controls the servo spool valve mechanically by means of a pivoted armature, which is connected to the spool by the valve-stroker link. The diagram also

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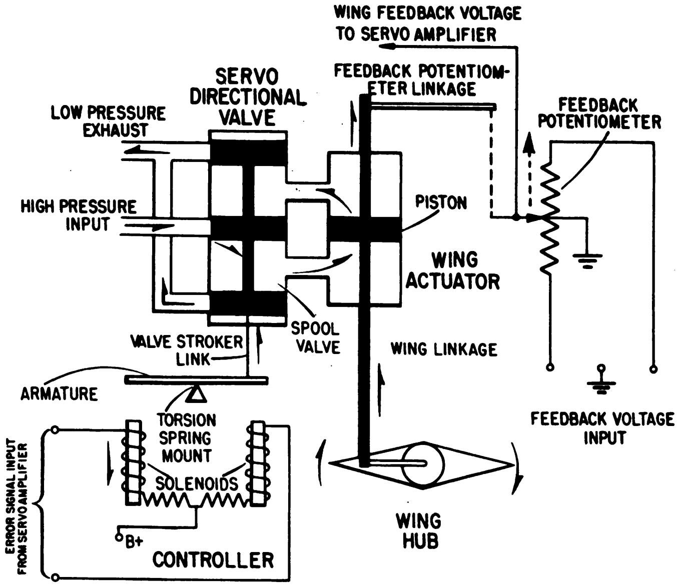

Figure 9–16.—Servo valve with mechanical control and wing actuator unit.

shows a wing actuator mechanically connected to a control surface and to a feedback potentiometer.

As in the hydraulically controlled valve, currents in the two solenoid windings develop either balanced or unbalanced magnetic fields. These fields act upon opposite ends of the armature, causing it to be displaced about a center mounting. Motion of the armature in either direction is opposed by a flat torsion spring, which is an integral part of the mounting.

In figure 9–16, the directions of liquid flow and the resulting action are indicated by arrows. Assume that the error signal applied by the servo amplifier causes a greater current flow in the left-hand solenoid than in the right. The stronger magnetic force developed by the left coil then swings the left end of the armature downward. The armature comes to rest at the position in which the magnetic attraction is balanced by the tension in the torsion spring. This motion is transferred to the spool valve, forcing it upward; and the flow indicated by the arrows then takes place.

Upward motion of the spool valve allows fluid to flow into

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the lower chamber of the actuator cylinder, forcing the piston upward. The liquid in the upper actuator chamber is then forced out and passes through the spool valve into the low-pressure return line. Control action resulting in downward movement of the spool valve would have the opposite effect: the pressurized fluid would flow into the upper actuator chamber while the lower chamber would be exhausted to the reservoir through the return line.

The wing actuator (fig. 9–16) converts the energy of the hydraulic fluid into motion of the enclosed piston. The piston, in turn, operates the movable wing through a mechanical linkage mounted within the wing hub.

The actuator piston also adjusts the position of the feed-back potentiometer, which produces a voltage corresponding in polarity and amplitude to the position of the wing. This voltage is coupled back to the input of the servo amplifier and subtracted from the wing-command signal supplied by the electronic control circuits. The resulting error signal governs the output voltage of the push-pull servo amplifier which controls the solenoids.

When the commanded position of the wing and the actual wing position are identical, the error signal is zero; and the output voltage of the servo amplifier is such that the solenoids are brought into magnetic balance. In this condition, the spool valve is centered; and no further change occurs in the positions of the actuator piston and of the wing.

The two servo-valve assemblies described above are examples of typical missile-borne hydraulic mechanisms. It is necessary now to consider an entirely different kind of device—one which is not a part of the missile but which is required in test sets associated with it. This is the pressure gage, a measuring instrument which occupies the same position with respect to hydraulic circuits as that of the voltmeter in the testing of electrical and electronic equipment.

The Bourdon Pressure Gage

The Bourdon gage is one of the oldest pressure-sensitive instruments and is used universally for measuring both liquid and gas pressures. Thus it is an element common to hydrau-

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lic and pneumatic systems. These gages give direct indications of pressure; they are simple in construction and in principle of operation; and when properly calibrated, they are reliable and accurate.

The principle of the Bourdon instrument and the basic construction can be understood by means of figure 9–17. The basic action is indicated in (A) of the drawing and can be stated simply as follows: When pressure is applied to a curved, hollow tube, it tends to straighten.

The tube is made of flexible metal; it is closed at one end and has a cross-sectional area which is approximately elliptical, or oval in shape. Liquid or gas under the pressure to be measured flows into the open end of the tube and the applied pressure increases equally on each square inch of the inside surface. As indicated in figure 9–17, the area of surface A on the outside of the curve is greater than the area of surface B on the shorter radius. Hence, the total force acting on A is greater than the force on B.

As a result of the difference of the opposing forces, the tube tends to straighten by bending in the direction of surface A; and the oval cross section tends to assume a more circular shape. The deflection of the tube continues until the difference of forces is balanced by the elastic resistance of the metal.

The principal working parts of a Bourdon gage are shown

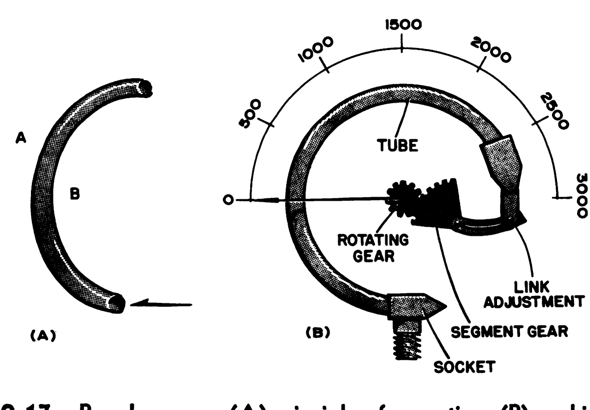

Figure 9–17.—Bourdon gage: (A) principle of operation; (B) working parts.

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in (B) of figure 9–17. The metal tube is bent to form the segment of a circle and is anchored at one end to the gage socket. The other end is closed and is connected through an adjustable linkage to a segmental gear, which meshes with a small rotating gear, or pinion. The latter gear rotates the shaft of the pointer across the gage dial.

When pressure is applied, the tip of the tube moves by a small amount, which within limits is directly proportional to the applied pressure. The motion is multiplied mechanically by the linkage so that a fairly small tip movement results in a sizable movement of the pointer. The dial is marked off in divisions which are approximately equal because of the proportional relation of the pressure to the resulting movement of the tube and pointer shaft.

Bourdon gages are made in many sizes and for various values of maximum pressure. Phosphor bronze, alloy steel, and stainless steel are typical tube materials. Instruments designed for high-pressure measurements ranging up to 10,000 pounds per square inch usually contain thick-walled tubes made of alloy steel. In gages used for low maximum pressures not exceeding 100 p. s. i., the tube is generally made of bronze. Tubes in high-pressure gages are of sufficient size that they can be threaded and screwed into the gage socket and tip assembly; while in low-pressure instruments, the connections are often made either by welding or by soldering.

When in use, Bourdon gages should be protected from excessive vibration, from abnormally high temperatures, from corrosive liquids, and from sudden application of high pressures. When the line connecting the gage to the system contains a petcock, this should be opened slowly, particularly if the system contains liquids with fluctuating pressures. Calibration of the gages is accomplished by applying known pressures from a standard source and by making subsequent adjustments of the pointer mechanism so that the known values are indicated exactly.

MISSILE PNEUMATIC SYSTEMS

Almost all air-launched missiles contain pneumatic systems, which employ hot or compressed gases as primary

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sources of power. Pneumatic power units are especially suitable for missile applications since they provide the means for liberating large amounts of energy from light, compact, and portable containers. Energy sufficient to meet the power demands of the control system during flight can be derived easily from small flasks containing highly compressed air or ~~else~~ produced by burning solid chemical fuel. The required energy can thus be stored until needed and then released to small pneumatic mechanisms. These either convert the energy directly into useful mechanical motion, or convert it into other forms such as hydraulic and mechanical power if either is required.

The operation of all missile pneumatic equipment is based on the physical characteristics of gases; and it is desirable that the trainee be familiar with certain fundamentals of gas physics before considering examples of practical pneumatic devices. The basic characteristics of importance are stated concisely in the GAS LAWS. These are general relationships which apply to all gases and which are usually given in the form of simple equations expressing the dependence of gas volume upon temperature and pressure.

The concepts of importance in the study of the gas laws are ABSOLUTE PRESSURE, GAGE PRESSURE, and ABSOLUTE TEMPERATURE. These are discussed in the pages immediately following, after which a discussion of the gas laws is given together with a few representative problems to illustrate their application in practical cases. The concluding portion of the section is devoted to examples of missile pneumatic equipment.

Absolute and Gage Pressures

Pressure, like any other quantity, may be measured with respect to any selected reference, or standard. Two references are commonly employed in expressing gas pressures. These are (1) absolute zero, and (2) the pressure of the local atmosphere.

If the pressure of a gas is expressed as a difference between its real value and the pressure of a complete vacuum, the measured value is called an ABSOLUTE PRESSURE; and the

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quantity measured is the total force present upon each unit of area. An example is the figure usually taken as the average value of the atmospheric pressure at sea level, which is 14.7 pounds per square inch.

When a given pressure is expressed as a difference between its absolute value and that of the local atmospheric pressure, the measurement is called a GAGE PRESSURE. Bourdon gages designed for pneumatic measurements give this type of indication because of the basic construction involved: atmospheric pressure is present on the inside of the curved tube even when no applied pressure is present from the system measured. Upon application of a pressurized gas, the tube then deflects in proportion to the applied pressure relative to that of the surrounding atmosphere.

In computations in which pressure is a factor, gage pressures must be converted into absolute values. This is done simply by adding the local atmospheric pressure to the gage pressure. When the values are given in pounds per square inch, the rule can be stated in this way: absolute pressure equals gage pressure plus 14.7 p. s. i.

Absolute Temperature

THE KINETIC THEORY OF GASES.—Like pressure, the temperature of a gas can be measured with respect to an absolute zero value. This value, which is usually expressed in terms of the centigrade scale, represents one of the fundamental constants of physics. It was established experimentally during a series of tests made in the study of the kinetic theory of gases.

According to this view, a gas, like other forms of matter, is composed of molecules, or small particles made up of combinations of atoms. Normally, the molecules of any substance are in constant motion; but in the gaseous state, the motions are assumed to be entirely random. That is, the molecules are free to move freely in any direction and are in constant collision, both among themselves and with the walls of the container. The moving particles possess energy of motion, or kinetic energy, the total of which is equivalent to

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the quantity of HEAT contained in the gas. When heat is added, the total kinetic energy is increased. When the gas is cooled, the thermal agitation is diminished and the molecular velocities are lowered.

The molecules do not all have the same velocity, not even in the same gas, but display a wide range of individual velocities. The TEMPERATURE of the gas, according to the kinetic theory, is determined by the average energy of the molecular motions. PRESSURE is accounted for by considering it as resulting from the bombardment of the walls of the container by the rapidly flying molecules. The particles are considered as approximating the ideal condition of perfect elasticity, so that they rebound from the walls with essentially the same velocities with which they strike them.

In accordance with the kinetic theory, if the heat energy of a given gas sample could be reduced progressively, a temperature would be reached at which the motions of the molecules would cease entirely. If known with accuracy, this temperature could then be taken as a natural reference, or a true absolute zero value. It was the purpose of the experiments mentioned above to establish the existence and value of this condition of temperature, which was predicted by the kinetic theory.

ABSOLUTE ZERO.—The tests were made with hydrogen. Since any change in the temperature of a gas causes a corresponding change in the pressure, it was necessary to consider temperature, pressure, and volume together. The hydrogen was enclosed in a cylinder containing a movable piston so that the volume could be adjusted to maintain the initial pressure. The experiment was started with the gas at a temperature of 0° C.

It was found that when the gas was cooled enough to drop the temperature by 1° C., the volume had to be decreased by moving the piston in order to keep the sample at the same pressure. The new gas volume was then equal to 272/273 the volume at 0° C. And as the temperature was lowered further, the volume (for constant pressure) decreased by an amount equal to 1/273 the initial volume for each decrease of one centigrade degree.

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If, however, the volume was kept constant (by keeping the piston unchanged in position), it was found that the pressure varied at the same rate. That is, it decreased by an amount equal to 1/273 the pressure at 0° C. for each change in the temperature of 1°.

The same rates of change of volume and pressure were found to be present in all gases and not in hydrogen alone; and in addition, they were uniform over a wide range of temperature. All these facts led to the conclusion that if any gas were cooled to −273° C. (actually −273.16°), with the pressure kept constant, the volume would shrink to zero. However, all known gases change to the liquid state before this temperature is reached and the volume-temperature coefficient for liquids is quite different from that of gases. Also, if the volume were maintained at the initial value, the pressure would approach zero as the temperature approached this same value. It was then assumed that −273° C. represents the theoretical absolute zero point at which all molecular motion ceases and no more heat remains in the substance to be extracted.

The existence of absolute zero cannot be determined directly by observing the volume of gas cooled to −273° C., since all gases are converted to the liquid state before this temperature is reached. In many experiments, however, this condition has been approached closely, the actual temperature reached being within a small fraction of a degree of the theoretical zero value.

THE KELVIN SCALE.—When temperatures are measured with respect to −273° C., they are said to be expressed in the absolute, or Kelvin, scale. Specific absolute temperatures are designated by the letter K. Thus, 0° C. is equivalent to 273° K.; 20° C. equals 293° K., and 100° C. equals 373° K.

In formulas, Kelvin temperatures in general are indicated by the letter T, thus:

$$T = C + 273,$$

where T is the temperature in degrees Kelvin, and C is the

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centigrade reading. To convert Fahrenheit temperatures into absolute, the formula becomes

$$T=\frac{5}{9}F+255.23,$$

where F is the Fahrenheit temperature.

In all problems involving gas temperatures, values given in centigrade or Fahrenheit must be converted to the absolute scale by means of these equations. Of these two, the former is the one more often employed since the absolute Fahrenheit scale is seldom needed.

Gas Laws

The basic laws governing gases can be expressed in simple formulas stating the general relations of volume, pressure, and temperature. One of the most important of these principles concerns the relation of gas volume to pressure. It has been known since the seventeenth century and is associated with the name of Robert Boyle, an English scientist of that time who first announced it.

BOYLE'S LAW.—Boyle was among the first to study what he called the "springiness of air." He learned by direct measurement that if the temperature of an enclosed body of gas is kept constant, the volume is reduced to half the former value when the pressure is doubled. As the applied pressure decreases, the resulting gas volume increases; or in general, the product of the volume and pressure remains constant. Boyle formulated the general law which can be stated as follows:

WHEN THE TEMPERATURE IS HELD CONSTANT, THE VOLUME OF ANY DRY GAS VARIES INVERSELY WITH THE APPLIED PRESSURE.

This can be expressed in equation form in two ways:

$$V_1P_1=V_2P_2, \text{ or}$$

$$\frac{V_1}{V_2}=\frac{P_2}{P_1}$$

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where V_1 and P_1 refer to the original volume and pressure, and V_2 and P_2 refer to the new volume and to the new pressure which causes it.

As an example, consider the following problem which involves Boyle's law. Nitrogen is confined in a container with a volume of 2 cubic feet. The pressure is 150 p. s. i., gage. If the gas is allowed to expand to a volume of 10 cubic feet with no change in temperature, what is the new value of gage pressure?

The gage reading must first be converted to absolute pressure by adding 14.7. The resulting value, the original volume, and the new volume are then substituted in the formula:

$$V_1P_1 = V_2P_2$$

$$(2)\ (150 + 14.7) = (10)\ (P_2)$$

$$P_2 = \frac{(2)\ (164.7)}{10}$$

$$P_2 = 32.94 \text{ p. s. i., absolute}$$

Converting absolute to gage pressure,

$$32.94 - 14.7 = 18.24 \text{ p. s. i., gage pressure; answer.}$$

Charles' law.—This law consists of two general statements which relate the temperature of a gas to (1) the volume with the pressure held constant, and (2) the pressure with the volume constant. The principle is named in honor of a French physicist, whose studies provided much of the foundation for the modern kinetic theory of gases. Charles found that all gases expand and contract in direct proportion to the change in the absolute temperature, provided the pressure is held constant. Expressed in equation form, this part of the law is given by

$$V_1T_2 = V_2T_1, \text{ or}$$

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

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where V_1 and V_2 refer to the original and final volumes; and T_1 and T_2 indicate the corresponding temperatures measured on the Kelvin scale.

Since the volume of a gas increases as the temperature rises, it is reasonable to expect that if a given mass of gas were heated, and yet confined in the same space, the pressure would increase. In the experiments described in a preceding section, it was found that the increase in pressure for any gas kept at constant volume was very nearly 1/273 of the pressure at 0° C. for each increase of one degree centigrade Because of this fact, it is convenient to state this relationship in terms of absolute temperature. In equation form, this part of Charles' law becomes

$$P_1T_2=P_2T_1, \text{ or}$$

$$\frac{P_1}{P_2}=\frac{T_1}{T_2}$$

In words, this states that with constant volume, the pressure of any gas varies directly with the absolute temperature.

The following problem illustrates Charles' law. An accumulator filled with nitrogen under a pressure of 2,000 p. s. i., gage, at a temperature of 25° C. is left in the sun. It heats to a temperature of 55° C. What is the new gage pressure?

The pressure and temperature data are converted into absolute values and substituted in the formula:

$$P_1T_2=P_2T_1$$

$$(2{,}000+14.7)(55+273)=(P_2)(25+273)$$

$$P_2=\frac{660{,}821.6}{298}$$

$$P_2=2{,}217.5 \text{ p. s. i., absolute}$$

Converting absolute to gage pressure:

$$2{,}217.5-14.7=2{,}202.8 \text{ p. s. i., gage; answer.}$$

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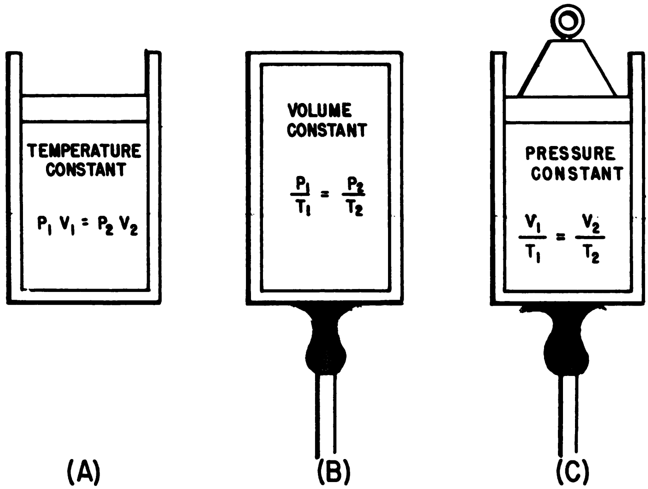

Figure 9–18.—The general gas law.

THE GENERAL GAS EQUATION.—The facts concerning gases discussed in the preceding sections are summed up and illustrated in figure 9–18. Boyle's law is expressed in (A) of the figure; while the effects of temperature changes on pressure and volume (Charles' law) are illustrated in (B) and (C), respectively.

By combining Boyle's and Charles' laws, a single expression can be derived which states all the information contained in both. This expression is called the GENERAL GAS EQUATION, a very useful form of which is given by the following:

$$\frac{P_1V_1}{T_1}=\frac{P_2V_2}{T_2}$$

It can be seen by examination of figure 9–18 that the three equations it contains are special cases of the general equation. Thus, if the temperature remains constant, T_1 equals T_2, and both these can be eliminated from the general formula, which then reduces to the form shown in (A). When the volume remains constant, V_1 equals V_2, thereby reducing the general equation to the form given in (B).

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Similarly, P_1 is equated to P_2 for constant pressure, and the equation then takes the form given in (C).

The general gas law applies with absolute exactness only to "ideal" gases in which the molecules are assumed to be perfectly elastic. However, it describes the behavior of actual gases with sufficient accuracy for most practical purposes. In the form given above, the equation involves six variable quantities, five of which must be known in order to find the sixth. As an example of its use, consider this problem in which it is required to find the gage pressure resulting from changes in both temperature and volume:

A certain gas has a volume of 4 cubic feet at a pressure of 150 p. s. i., gage. It is compressed to a volume of 2 cubic feet and heated from an initial temperature of 70° C. to 300° C. What is the final gage pressure?

The pressure and temperature data are converted to absolute values; these are substituted in the general equation; and the resulting expression is solved for P_2:

$$\frac{P_1V_1}{T_1}=\frac{P_2V_2}{T_2}$$

$$\frac{(164.7)(4)}{(70+273)}=\frac{(P_2)(2)}{(300+273)}$$

$$P_2=\frac{(164.7)(4)(573)}{(2)(343)}$$

$$=550.3 \text{ p. s. i., absolute.}$$

Converting absolute to gage pressure:

$$550.3-14.7=535.6 \text{ p. s. i., gage; answer.}$$

Pneumatic Equipment

Two classes of pneumatic equipment are employed in missile wing-control systems. In some missiles, the system consists entirely of pneumatic mechanisms, which convert the energy of expanding gas directly into mechanical motions

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of the wings. In these, the principal fluid mechanism is the GAS-POWERED ACTUATOR.

The second class of equipment is represented in the system shown in figure 9–2, which contains both pneumatic and hydraulic components. The pneumatic system releases the energy stored in compressed gas and converts this energy into a form suitable for driving the hydraulic pump. The units of principal importance in this class of pneumatic equipment are pressure REGULATORS and AIR MOTORS.

In both kinds of systems, pressurized gas serves as the prime source of energy for the entire wing-control section. In all-pneumatic control, the gas is usually provided by burning a chemical fuel in a small, closed container. Once ignited, the fuel burns with intense heat and liberates large quantities of vapor, which is raised to a high pressure by confinement in the limited space of the enclosure. It is then conducted to the power units, the wing actuators, which operate the control-surface linkages.

PNEUMATIC WING ACTUATORS.—Figure 9–19 is a simplified schematic representing a gas-actuated unit of the type used in missiles containing all-pneumatic wing servo systems. At missile launch, the chemical fuel is fired by the igniter; and the hot gas generated by the burning fuel enters the manifold, which conducts it to the two actuator cylinders.

Upon entering the cylinders, the vapor passes through the small holes running through each piston and exhausts to the surrounding air, provided the flapper valves located at the lower openings of the pistons are in the open positions. If either valve is only partially open or is closed altogether, the gas flow is restricted, and pressure builds up on the upper surface of the associated piston. Thus, the function of the valves is to govern the value of the pressure exerted upon the pistons during operation.

The valves are controlled magnetically by solenoid windings located in the pistons. A push-pull servo amplifier supplies the currents for the windings and hence governs the resulting magnetic fields which adjust the valve positions. When no error signal is present at the amplifier input, equal currents flow in the solenoids; the valves are then in similar

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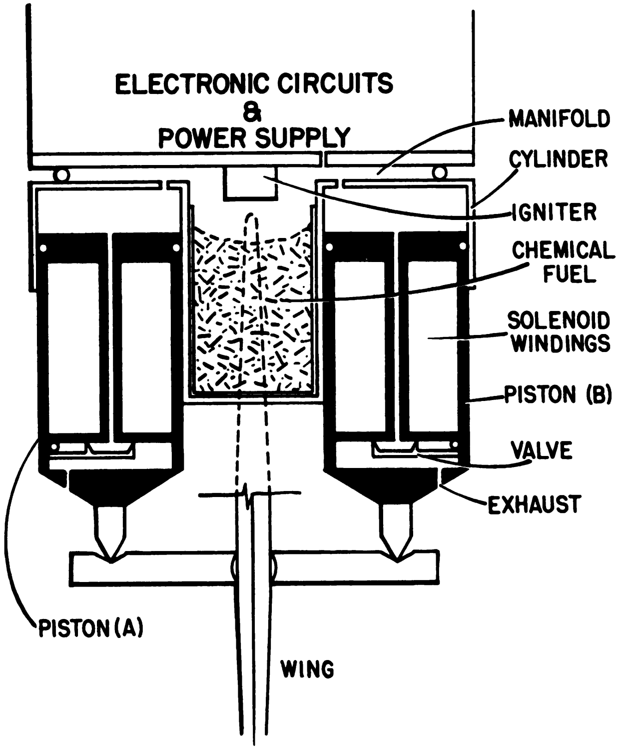

Figure 9–19.—Gas-actuated wing-control unit.

positions and exhaust the gas at equal rates; the pressures on both pistons are equal so that the two are balanced; and as a result, the wing is held fixed in position.

Assume that an error signal reaches the amplifier, causing it to increase the current in the solenoid of piston B. The stronger magnetic field that results operates to close the valve, and pressure rises on the top surface of the piston. At the same time, the current in the solenoid in piston A is decreased by the amplifier; and the corresponding valve opens, exhausts the gas rapidly, and lowers the pressure on the piston. The forces acting upon the two pistons are in opposition; and since that at piston B is no longer balanced by the counterforce on piston A, the former is pressed down-

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ward and the wing takes the new position demanded by the electrical error signal.

A reversal of polarity of the error signal causes the servo amplifier to reverse the previous current relation in the solenoids; and the pressure then developed on piston A is greater than the pressure on the other piston. In this case, piston A moves downward and the motion of the wing is opposite in direction to that described above. In general, the unit produces pressure differentials and converts these into wing positions in accordance with the applied electrical command signals.

Units of the type illustrated (fig. 9–19) are used in smaller missiles. They have the advantages of compactness and light weight; and because of the simplicity of operation, the entire power equipment needed for control of the vehicle in one axis can be mounted as a single physical assembly.

Pressure regulators.—Pneumatic regulators are used to provide air or other gases at constant pressure when the primary supply pressure fluctuates or when it is at a higher value than is required by the working units of the system. Most regulators operate by means of a spring-loaded valve through which the gas must pass and which produces a pressure drop, or difference between inlet and outlet pressure values. The valve opening can be adjusted automatically so that the pressure drop is varied when either the input or outlet pressure changes.

The regulator shown in figure 9–20 operates by controlling the pressure drop across a variable, ring-shaped orifice, or opening, between a poppet valve and the valve seat. In the absence of air pressure at the inlet port, the compression spring in the piston shell acts so as to hold the valve open so that minimum pressure drop results when the air begins to flow. When air is admitted through the inlet, it passes through the orifice and builds up pressure on the effective area of the piston at the outlet side of the regulator. As the outlet pressure rises, the piston moves against the spring, reduces the valve opening, and causes a throttling effect to take place by increasing the pressure drop.

The piston moves until the force of the spring exactly

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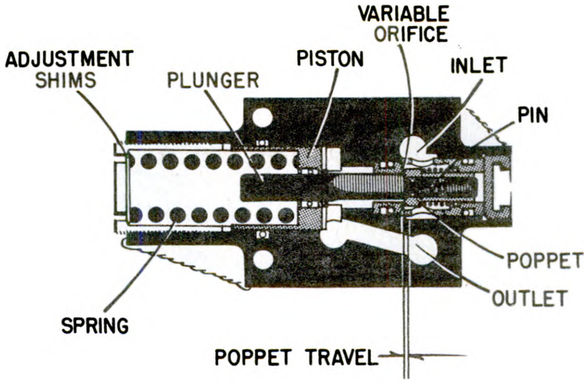

Figure 9–20.—Pneumatic pressure regulator.

balances the force developed by the outlet air pressure. In this condition of equilibrium the orifice opening remains fixed and the pressure drop constant. This continues until some pressure change occurs which results in a readjustment of the pressure drop as the variable orifice is either opened or closed by motion of the piston.

In the unit shown (fig. 9–20), the outlet pressure value can be adjusted by adjustment of the spring tension. This is done either by rotating the threaded end plug or by using adjustment shims in the spring support.

THE AIR MOTOR.—The motor illustrated in figure 9–21 represents the type of component used to change the pneumatic energy stored in an air flask into rotary motion. The assembly contains a slotted rotor mounted eccentrically, or off center with respect to the enclosing cylindrical chamber. The rotor has six fiber vanes mounted in the slots, which are equally spaced around the circumference. The vanes are able to move radially, and the edge of each is held against the wall of the chamber. Because of the eccentric mounting, as the rotor turns, the vanes move inward or outward from the rotor center; and the exposed area of each vane increases to maximum and diminishes to a minimum value during each revolution.

The physical construction of the air motor is shown in the

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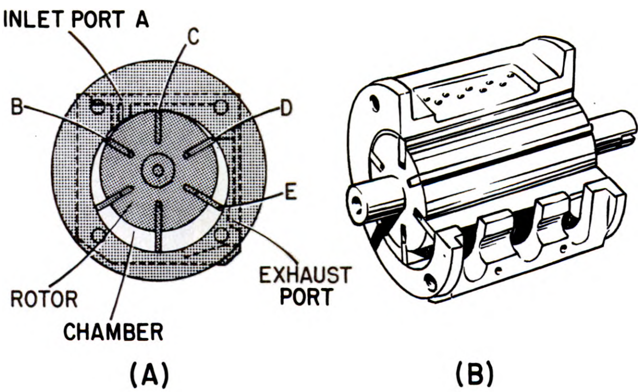

Figure 9–21.—Air motor: schematic and cutaway drawings.

cutaway drawing in figure 9–21, and the method of operation can be understood by means of the schematic. Air enters the motor chamber through the inlet port at point A; and pressure is exerted against the chamber walls, the rotor, and on the exposed areas of vanes B and C with the rotor in the position shown. In this position, the area presented by vane B is greater than that of vane C; and it is this difference in area which causes the rotor to turn in the direction indicated by the arrow. The pressure is equal on both vanes, but the total force acting on B is greater than the force on C because of the difference in areas.

As the rotor moves, vane C increases in area; and after a rotation of about 80 degrees, the space between vanes B and C is isolated from the input port. In this position, the area of vane C is larger than that of vane D, and the same action takes place that occurred with B and C. When vane E is brought under the input port, the pressure between vanes B and C is exhausted as the air passes out through the exhaust port.

The differential area principle operates continuously as each adjacent pair of vanes comes under the input port so that each set of vanes contributes to rotary motion in the direction illustrated (fig. 9–21). Motors of this type develop speeds in the order of 2,500 to 4,000 revolutions per minute

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and require input pressure in the approximate range of 75 to 150 pounds per square inch.

The examples of pneumatic and hydraulic mechanisms given in this chapter are taken largely from the field of missile-borne control equipment. Additional information concerning these kinds of equipment can be found in other parts of the course. Appendix II contains the basic schematic symbols used in drawings representing hydraulic and pneumatic systems; while the following chapter includes examples of the fluid devices used in missile electrical systems.

QUIZ

1. The wing servo units provide the __________ for the missile control system.
   a. brains
   b. errors
   c. muscles
   d. hydraulic pressure

2. A major component for a basic hydraulic servo system would be a/an
   a. accumulator
   b. feedback
   c. error detector
   d. solenoid

3. One of the fundamental characteristics of a fluid is
   a. compressibility
   b. its molecules
   c. the property of volume
   d. shapelessness

4. If it takes 10 p. s. i. to move a piston with an area of 15 square inches, what would the necessary force be if the pressure remained constant and the area increased to 25 square inches?
   a. 1,000 p. s. i.
   b. 150 pounds
   c. 250 pounds
   d. 250 p. s. i.

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5. The law that states, "increases in the pressure applied to a confined liquid are transmitted equally throughout," is part of ________ law.
   a. Pascal's
   b. Boyle's
   c. Charles'
   d. Kelvin's
6 A hydraulic jack has a ratio of 10 to 1. This means
   a. the applied force is multiplied 10 times
   b. it will lift 10 times its own weight
   c. the areas of the 2 pistons are 1 inch and 10 inches
   d. it will work 10 times harder
7. Hydraulic apparatus can be used to
   a. advantage due to the compressibility of liquids
   b. increase or decrease input force
   c. increase work output
   d. multiply work as opposed to force
8. The advantages and disadvantages of a hydraulic system are many. One of the disadvantages is
   a. pressure is uniform throughout the system
   b. small leaks cause the entire system to fail
   c. losses through friction are small
   d. variations in load have little effect on system
9. An essential property of a good hydraulic fluid is its ability to
   a. absorb impurities
   b. remain shapeless
   c. congeal
   d. reduce friction
10. The viscosity index of a crankcase oil for an auto would be approximately
   a. 110–140
   b. 0–30
   c. 80–100
   d. 20–30
11. The two types of hydraulic tubing used for missile systems are
   a. rigid tube, flexible hose
   b. copper, rubber
   c. steel, galvanized iron
   d. aluminum, copper
12. Systems using pressure of 2,500 p. s. i. would use ________ for tubing.
   a. synthetic rubber
   b. aluminum alloy (61ST)
   c. copper
   d. synthetic rubber covered with fabric braid

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13. Hydraulic fittings colored blue are manufactured

a. from aluminum
b. for mineral oil only
c. from steel
d. for pneumatic systems only

14. A micron is a unit of length equal to

a. 0.000001 centimeter
b. 1 millionth of a meter
c. 0.0000001 meter
d. 0.00039 inch

15. Micronic filters are used in

a. hydraulic systems only
b. pneumatic systems only
c. both hydraulic and pneumatic systems
d. hydraulic systems using water only

16. A diaphragm-type accumulator is used

a. in a closed system only
b. in a pneumatic system
c. usually in an open system
d. all of the above

17. The purpose of a __________ is to allow free flow in one direction and restrict flow in the opposite direction.

a. relief valve
b. restrictor
c. control valve
d. check valve

18. A servo spool valve is operated automatically by

a. valve controllers
b. manual means
c. mechanical linkage
d. the control system

19. Fixed orifices can be likened to a __________ in an electronic circuit.

a. fixed capacitor
b. fixed resistor
c. variable potentiometer
d. inductance coil

20. The Bourdon pressure gage is one of the __________ pressure-sensitive instruments.

a. newest
b. least accurate
c. oldest
d. most delicate

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21. The Bourdon gage gives an indication of
    a. atmospheric pressure
    b. pressure in terms of pounds per inch
    c. applied pressure minus atmospheric pressure
    d. applied pressure

22. The tubes used in gages for high pressure are usually made of
    a. iron
    b. copper
    c. bronze
    d. alloy steel

23. In computations in which pressure is a factor, gage pressure must be converted into
    a. absolute values
    b. atmospheric pressure
    c. simplified terms
    d. pressure at sea level

24. A temperature of 150° Kelvin is equal to __________ centigrade.
    a. 123°
    b. −123°
    c. −189°
    d. +189°

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CHAPTER 10

ELECTRICAL POWER SUPPLIES FOR GUIDED MISSILES

A guided missile is made up of a number of separate systems, each of which releases or controls energy in some form. The kinetic energy imparted by the rocket motor, the explosive potential of the warhead, the hydraulic or pneumatic energy put into play by the control-surface servos are all essential to the operation of the weapon as a whole. While in flight, the missile is a physically independent vehicle; and hence it must carry various units which serve as primary sources of the energy expended by the inner components during the brief interval of its active life. Among these sources is the electrical power system, which provides voltage for the numerous electronic and electrical devices usually required for guidance and control.

The design of suitable power supplies has been one of the major problems in missile development. The choice of the proper unit for a particular missile is dependent upon a large number of conditions. The quantity and types of the electrical components of the missile establish the basic requirements of the power supply. The operational life of the missile, its tactical utilization, and the manner of shipping and storage are major factors in setting the basic requirements of the components.

The electrical power needed in air-to-air and air-to-surface missiles varies over a range of approximately 100 to 2,000 watts, depending largely upon the type of guidance employed. In addition, the following characteristics are necessary for satisfactory operation. The power supply must be able to undergo long storage life during which little or no attention is

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required. It must have fast actuation time. It must be designed for a short active life; and since it is part of a "one-shot" system, it should be as simple as possible. It must have small physical size and light weight; and it should be able to supply voltages of many different values which remain substantially constant under varying load conditions.

In smaller missiles, such as those of the air-launched class, there are, in general, three kinds of loads which must be supplied with electrical power. These are electronic circuits, purely resistive loads, and electromechanical loads. Electronic-component loads are those which are supplied by the rectifier circuits with d-c voltages up to 1,000 volts. The resistive loads consist mainly of electron-tube filament circuits. The electromechanical loads are more difficult to define since they differ considerably from one missile to another; however, they usually include gyros, magnetic amplifiers, and the control elements of the servo valves.

Most of the load components are voltage sensitive; that is, the circuit operation changes with variations of the applied voltage. As a result, voltage regulators are a necessary part of most missile power supplies. As a rule, the load components which operate directly on a-c power are not extremely sensitive to variations in supply frequency. From considerations of size and weight, the a-c frequencies used in missile supplies tend toward higher values than are usually employed in conventional equipment. The use of higher supply frequencies permits the use of smaller transformers and filters; and the physical size of devices such as magnetic amplifiers can be less, while the response improves, up to a point, when the applied frequency is increased.

TYPES OF ELECTRICAL SYSTEMS

There are two basic types of electrical systems used in missiles to meet the general requirements given in the preceding paragraphs. These can be termed STATIC and DYNAMIC systems. In the former, electrical power is produced originally by chemical action, the primary source being one or more batteries. Dynamic power supplies are those in

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which rotating machines provide mechanical energy which, in turn, is converted into electrical energy by means of generators. In this type of system, the machine supplying the rotary motion is called a PRIME MOVER. It may be any one of several kinds of devices: electrical, hydraulic, pneumatic, or mechanical.

In figure 10–1, the fundamental components of a static or battery operated power supply are illustrated in simplified block-diagram form. Both d-c and a-c voltages are provided since both are usually required by the various elements comprising the resistive, electromechanical, and electronic loads. The battery, serving as the prime source, supplies low d-c voltage directly to the filament circuits, to various relays and solenoids, and to the secondary device, which in this case is a vibrator.

By the action of the vibrator, the low d-c input voltage is converted into a fluctuating or pulsing voltage which can then be increased in value by the step-up transformer, an essential part of the system shown in figure 10–1. The resulting high-voltage a. c. is applied to the motors of the missile gyros and to the input terminals of several conventional rectifier circuits. These provide the high d-c potentials required in the amplifiers, oscillators, and other electronic circuits used throughout the missile system.

In typical static power supplies, both dry-disk and electronic rectifiers are used. The number of separate rectifier circuits employed is determined by the number and requirements of the load elements present. Various values of d-c voltage are usually provided, some of which are positive and

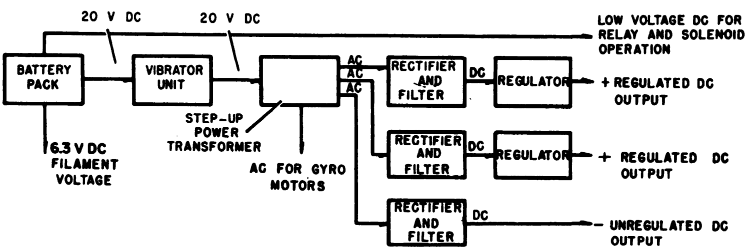

Figure 10–1.—Missile power system utilizing batteries and vibrator.

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some negative with respect to ground. As indicated in figure 10–1, some of the rectifiers are equipped with voltage regulators, which maintain the outputs at constant values as required when supplying voltage-sensitive load devices. Other rectifier units are often included which supply unregulated outputs.

A basic dynamic power supply employing rotating machines to develop electrical energy is illustrated in the block diagram in figure 10–2. While supplying the same types of loads as the battery-operated supply, this system is capable of developing power in considerably greater quantity. The initial voltage is furnished by an alternator, or a-c generator, which is driven through a mechanical coupling by a turbine. The turbine is energized by hot, compressed gas produced by burning a solid-propellant charge in an enclosed chamber; and the resulting rotation of the turbine imparts rotary motion to the alternator.

In typical examples of power systems of the type shown in figure 10–2, the alternator output voltage is 115 volts, three-phase, with a frequency of 400 c. p. s. This voltage is converted by transformers to the various values needed in the equipment supplied. As shown in the diagram, the filaments of the missile electronic circuits are supplied low-voltage, a-c power. The d-c relays and solenoids are powered

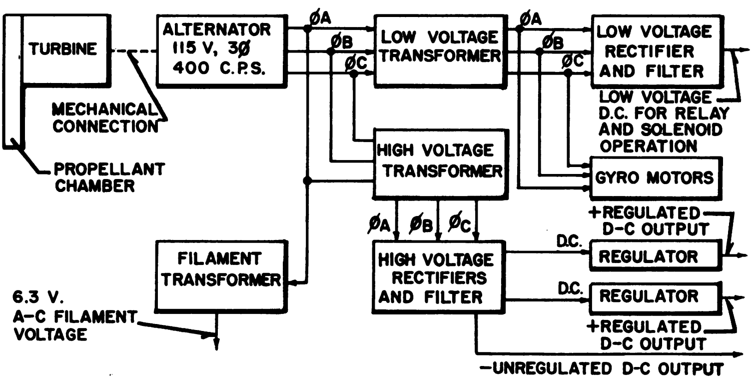

Figure 10–2.—Missile power supply utilizing rotary equipment.

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by means of a low-voltage rectifier circuit coupled to a transformer of appropriate turns ratio. This same transformer is often used to provide a-c energy for operating the gyro motors. High d-c voltages for the electronic circuits, as in the static system, are derived from rectifier units, both regulated and unregulated.

Many of the components and circuits used in missile power systems are conventional and are widely used in other kinds of power equipment. Most of these are discussed in detail in the companion texts of this course, *Basic Electricity*, NavPers 10086, and *Basic Electronics*, NavPers 10087. Reference will be made to these books in the course of the present discussion; and the chapters specifically mentioned are considered essential for an understanding of the subject. It is emphasized that for the trainee these chapters in the basic texts constitute required additional reading. The principal components of the systems illustrated in figures 10–1 and 10–2 are discussed in the following pages, in which the basic unit considered first is the primary source in static systems, the missile battery.

BATTERIES

In missiles in which the power demands of the guidance system are not excessive and in which electrical power is needed for a very short length of time, a battery pack may be used to furnish all the electrical energy needed in the operation of the weapon. In missiles of this kind, the total power demand is about 200 watts or less; and in these, the battery pack is used primarily to provide voltage for filaments, for secondary devices, and for units such as relays and solenoids.

Another important application of batteries in missiles is in telemetering equipment such as that described in chapter 11 of this text. In the experimental stage of a missile's development, numerous data gathered during actual flight are telemetered by special radio equipment from the missile to a ground station for recording and analysis. The power supply of the telemetering transmitter, carried in the missile, usually consists of a battery pack.

As explained in chapter 2, *Basic Electricity*, NavPers

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10086, there are two kinds of battery cells: primary and secondary. Both types of cells have been used in batteries designed for missile use. These batteries have been developed especially for this application and have as many of the following characteristics as possible: small physical size, high charge capacity, long shelf life, short activation time, and the ability to withstand large variations in temperature without materially changing in output voltage.

While no single battery meets all these requirements completely, as a result of extensive research and development, several kinds of cells of the RESERVE type have been brought forth for missile application. Among these are the silver-zinc cell and the nickel-cadmium cell, the former being the type most generally favored in missile design.

SILVER-ZINC BATTERIES.—A reserve cell, an example of which is the silver-zinc cell, may be defined as one which is maintained in the dry state until the time of its use. At this time, the cell is activated by adding the electrolyte solution. Once the solution has been added, the battery made up of reserve cells is ready for immediate use and requires no further charging. Most batteries of the silver-zinc type are not rechargeable. Once the electrolyte has been added the battery must be used within a certain specified time or else discarded.

A silver-zinc battery designed for missile use is shown in figure 10–3. The negative plates are composed of silver peroxide; the positive plates are made of zinc; and the electrolyte is a solution of potassium hydroxide (KOH) in water. Consisting of five cells, the battery illustrated has a terminal voltage of 7.0 volts. It weighs less than one pound and measures 2.5″ x 2″ x 2″.

ACTIVATION.—The battery shown in figure 10–3 has a very short shelf life when activated, and hence, no electrolyte is added to the cells until just before installation in the missile. To activate the battery, a hypodermic syringe, complete with needle, and an additional needle are used. The syringe is filled with about 11 cubic centimeters of electrolyte solution and inserted into the rubber grommet with which the battery cell is closed. The additional needle

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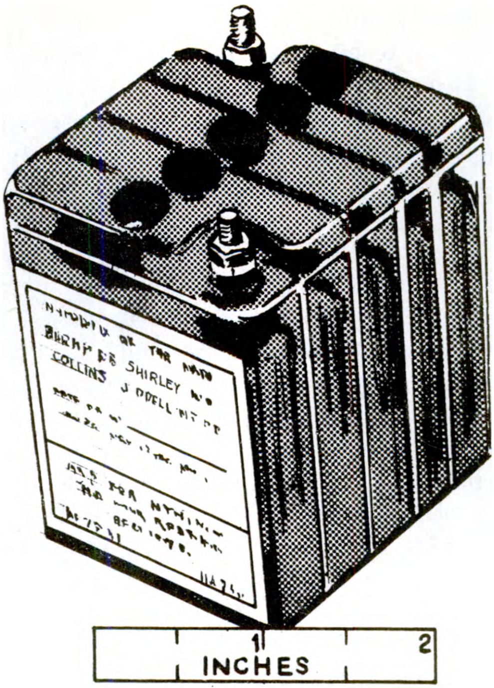

Figure 10–3.—Silver-zinc battery.

is inserted into the grommet also and serves to vent the air in the cell as the electrolyte is forced from the syringe. Each cell of the battery is filled in this way, with the solution being forced in at a slow, steady rate. Care must be taken not to spill any of the liquid on the skin, clothing, or on any of the nearby equipment. After filling all the cells, the battery must then be tested under a simulated full load prior to installation in the missile. Special battery tests have been developed for this purpose which are discussed in the chapter of this text dealing with missile testing.

Silver-zinc batteries larger than the unit illustrated, weighing up to six pounds, and delivering both 28 and 7 volts have been developed for use in missiles. Many of the of the larger batteries have a self-actuating feature which eliminates the need of manual filling. Also, usually included

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is a small heating system which operates either by chemical or electrical action to bring the battery elements up to operating temperature quickly when the cells are activated.

The battery elements are mounted in hermetically sealed, steel containers which enclose, in addition to the dry battery cells, an electrolyte chamber, a bottle of compressed nitrogen, and the heating unit. To activate a battery of this kind, an electrical impulse is applied to a mechanism which releases the compressed nitrogen in such a way that it forces the electrolyte solution into the cells. At the same time, the heating elements are put into action; and the battery elements are brought up to operating temperature almost immediately. In batteries which contain electrically controlled heating elements, the temperature of the battery is maintained at a constant value by the action of thermostats. The physical construction of these batteries is such that they are able to withstand high accelerations and to operate effectively in spite of the shock, vibration, and extreme temperature variations present in missile flight. The hermetically sealed containers prevent the escape of electrolyte and of gas generated by the battery cells.

Batteries made up of nickel-cadmium cells are also widely used in guided missiles. These cells produce an average terminal voltage of 1.2 volts each on discharge at normal current. The active material on the negative plates is a mixture of cadmium and iron. The positive plates contain nickel oxide as the active material. The electrolyte is a water solution of potassium hydroxide. Nickel-cadmium batteries have high retention of charge and can deliver current at comparatively high rates on discharge. They are superior to most other kinds of batteries for operation at low temperatures.

VIBRATORS

As stated previously, batteries alone are impractical for providing the high d-c voltages required in electronic circuits and other missile equipment. When batteries form the primary power source, it is, hence, necessary that SECONDARY POWER DEVICES, such as vibrators or rotating machines,

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be employed to convert the low source voltage into higher values. Examples of secondary power devices can be found in other systems, such as the power supply of an automobile radio or the electrical system of an aircraft. In the former, the high voltage needed is derived from a storage battery which supplies a vibrator pack and a step-up transformer. The resulting voltage is then rectified for use in the circuits. In airborne equipments, the necessary voltages are usually supplied by machines, such as inverters, dynamotors, and alternators.

In a similar manner, vibrators and generators are used in missile systems; and in these, the basic components are essentially the same as those used in automobiles and aircraft. The principal differences are largely in the physical size of the units and in the methods employed to drive the rotating equipment.

Basic vibrator.—A vibrator is a device of the interrupter type, similar in many respects to a buzzer or to a doorbell. It is not in itself a source of power, its primary function being to convert d-c voltage into a fluctuating potential.

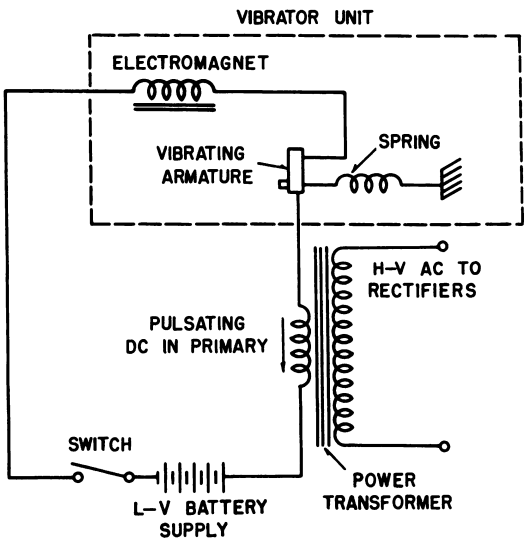

Figure 10–4.—Basic vibrator circuit.

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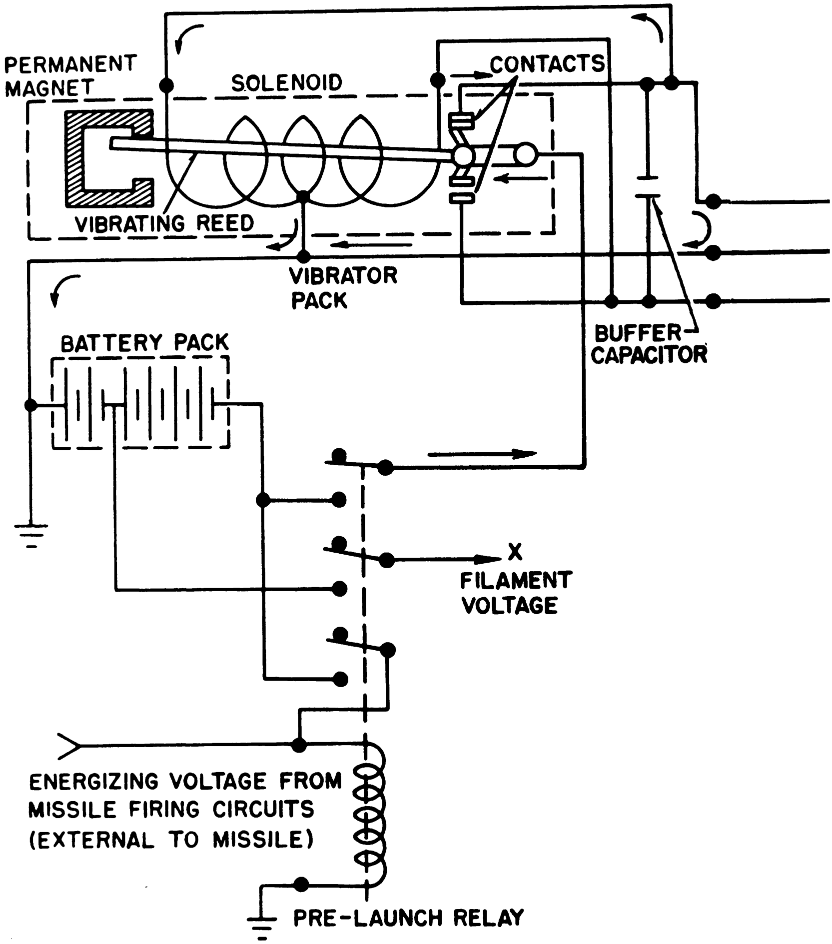

Figure 10–5.—Schematic diagram of basic vibrator power supply.

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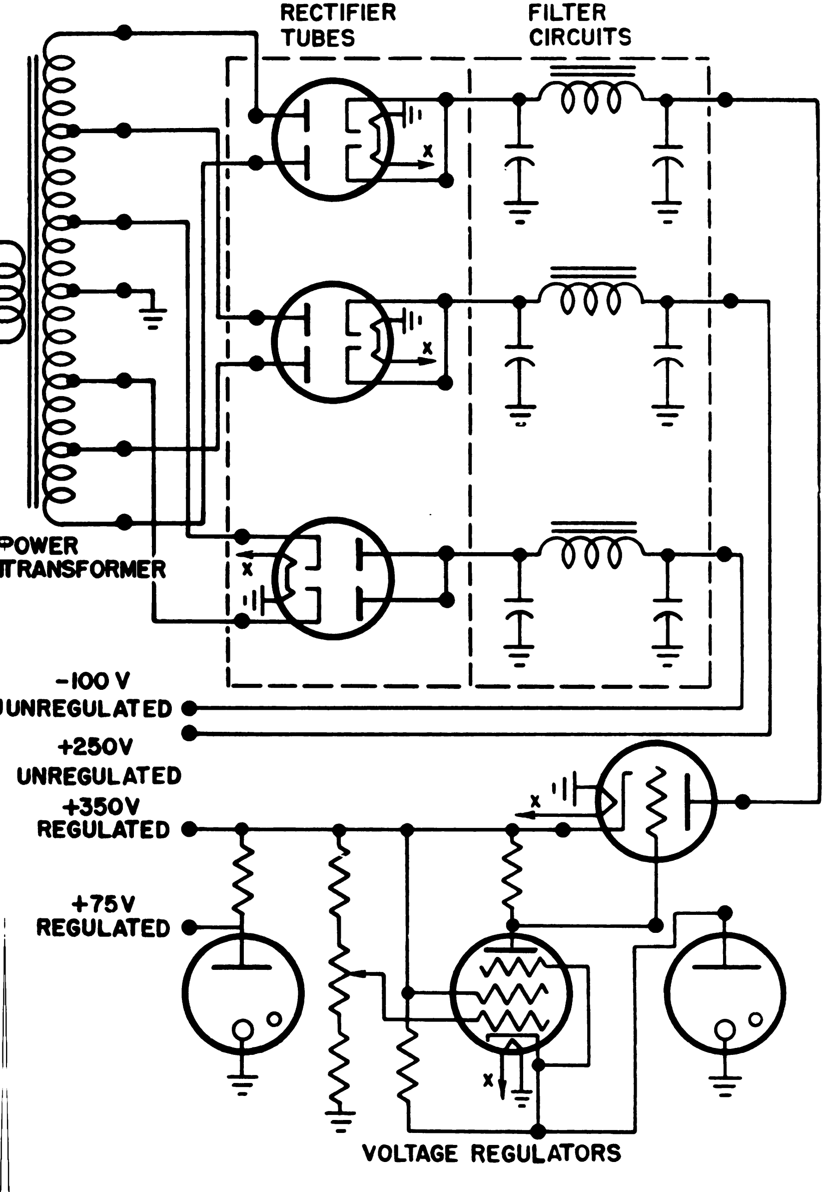

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It is useful mainly in systems which deliver comparatively small amounts of current at high voltage.

Figure 10–4 shows a simple vibrator circuit containing a battery and a transformer. When the switch is closed, current flows from the battery through the electromagnet in the vibrator unit, then through the contacts closed by the vibrating armature, through the primary winding of the power transformer, and back to the battery. In passing through the electromagnet, the current produces a magnetic field which attracts the armature. As the armature moves, it breaks the circuit; and when this occurs, the magnet can no longer attract the vibrator armature so that it is pulled by spring tension back to the original position in which the circuit is closed.

This action is continually repeated so that the circuit is alternately made and broken and pulsating direct current flows in the transformer primary. The resulting magnetic fields within the transformer, linking the primary winding with the secondary, induce the desired high-voltage a-c output.

A vibrator of a more elaborate type is shown in figure 10–5, a schematic diagram of a missile power supply. The primary source, a battery pack supplies two d-c voltages. The vibrator and a power transformer comprise the secondary power devices. The remaining components include full-wave electronic rectifiers with associated filters, and a regulator circuit containing voltage-regulator tubes.

The action of the vibrator and the other components is initiated by the prelaunch relay, shown in figure 10–5 in the deenergized position. Just prior to launching, the prelaunch relay is energized by a voltage produced by the launching circuits. One set of relay contacts then routes a holding voltage from the battery pack to the relay to keep it energized after removal of the launching voltage. Another set of contacts completes the circuit from one section of the battery pack to the tube filaments. A third set of relay contacts applies voltage to the vibrator and hence to the primary of the power transformer.

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The arrows in figure 10–5 representing electron flow indicate that as the vibrator circuit is closed, current is conducted through the contact on the vibrator reed and then both to the encircling solenoid and to the transformer. The reed is made of magnetic material and forms the core of an electromagnet. When current flows in the solenoid, a magnetic field is set up in the reed in such polarity that the reed is repelled from the permanent magnet against which it has been held. The reed moves so as to open the associated contact and to interrupt the flow of current in the transformer primary winding. As the magnetic field produced by the primary collapses, high voltage is induced in the secondary winding; while at the same time, the field around the vibrator solenoid is removed.

The vibrator reed moves through the center position and comes to rest when it closes the lower vibrator contact. With this contact closed, current flows in the other half of the transformer primary and in the other half of the vibrator solenoid. The reed is then magnetized in such a polarity as to cause repulsion from the lower position; and again, a magnetic flux is produced in the transformer winding which induces a voltage in the transformer secondary.

As a result of the vibrator action, a series of voltage fluctuations which are approximately square topped in waveform appears at the input of the transformer, producing at the secondary terminals recurring cycles of a-c voltage much higher in value than the applied potential.

The buffer capacitor across the primary of the power transformer is an essential part of the system. It serves to give a smooth crossover of the applied voltage at the instant the vibrator contacts open. Hence, it prevents arcing at the contacts and also eliminates high-frequency transient voltages which would otherwise be produced when the contacts make or break. A buffer capacitor may be placed either across the primary as shown in figure 10–5 or across the secondary of the transformer. In the latter position, smaller values of capacitance may be used because of the higher value of the voltage in that circuit.

The secondary of the transformer is tapped to provide

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several values of a-c voltage for the three rectifier circuits. These, together with the conventional "pi" filters used to minimize ripple, provide the required d-c voltages, one of which is negative and two positive with respect to ground. A series-type regulator is employed to provide two regulated outputs. The remaining voltages are routed directly to the load circuits. The full-wave rectifier circuits, the filters, and the series regulator (including V–R tubes) shown in figure 10–5 are discussed at length in chapter 3, *Basic Electronics*, NavPers 10087, to which the reader is referred for an explanation of these parts of the power supply.

ROTATING ELECTRICAL EQUIPMENT

The electric generator is the basic rotating device used in missile power systems. Missile generators may be either a.c. or d.c. or a combination of the two. These machines are, in most cases, specially designed to meet the requirements of missiles and are used either to supplement or to replace the battery pack. In systems in which the battery is eliminated entirely, the generator is driven by a prime mover such as a turbine, a hydraulic motor, or in some instances, by an airscrew. In missile supplies in which the rotating equipment supplements the battery, one or more generators are driven by low-voltage, d-c motors. In these systems, the generating equipment often consists principally of inverters or dynamotors. In both of these kinds of machine, the motor and generator units are sections of a single physical unit, being mounted in a single housing.

Basic Types of Generators

Introductory information concerning electric generators is contained in *Basic Electricity*, NavPers 10086, chapters 10, 12, and 14, which treat d-c generators, a-c principles, and alternators, respectively. The equipments illustrated in the basic text are much larger than those employed in missiles, but the underlying principles discussed there are common to all types, both large and small; and it is this information which is of primary importance for the trainee.

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Principle of operation.—The basic principle upon which the operation of both d-c and a-c generators depends is that of electromagnetic induction. It may be expressed briefly as follows: an electromotive force, or voltage, is induced in any conductor linked with magnetic flux lines when the number of flux linkages changes with time. Thus, in a simple generator, consisting of a coil which can be rotated in a constant magnetic field, voltage is induced in the coil as it turns, thereby varying the quantity of flux lines linking it. The value of the induced voltage at any instant is proportional to the number of turns in the coil and to the rate at which the flux linkage is changing at that instant. If the coil rotates at a steady speed, the rate of change of the flux linkage becomes zero, positive, and negative during the course of one revolution. Hence, a graph of the induced voltage resulting from one complete revolution would appear as a sine wave, or an alternating function, rising from zero to a positive peak, then falling to zero, followed by a rise in negative polarity, and falling again to zero.

The induced voltage appears irrespective of whether the coil moves and the magnetic field remains stationary, or whether the field is moved with respect to the coil. The necessary factor is that there be a definite rate of change of the flux linking the conductor.

The primary difference between d-c and a-c generators, both of which operate on the same basic principle, is the manner in which the induced voltage is taken from the coil. That part of the machine which supplies the magnetic flux is called the field; and that part in which the voltage is induced is known as the armature. In the d-c generator, the armature is almost always the driven or moving member referred to as the rotor, as distinguished from the nonmoving member, the stator. The output voltage is taken from the armature by means of brushes which are held in contact with a commutator, a segmented wheel on the rotor. The commutator is a mechanical rectifier, which converts the alternating current generated in the moving coils into a current which flows in a single direction through the load.

In alternators, or a-c generators, two types of basic

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construction are used. In some machines, sliding contacts, or sliprings, are used to connect the generated voltage to the load. The armature of this type of alternator is the rotor and the field is the stator. A more frequently used method of construction is that of the revolving field alternator, in which the armature remains stationary while the field comprises the rotor element. In these, the output voltage can be connected directly to the external load circuit, no sliprings or sliding contacts being necessary.

ALTERNATORS.—Alternators can be classified according to the manner in which the voltage is induced in the armature; and according to this method of division, they fall into the following classes: SYNCHRONOUS, INDUCTION, and INDUCTOR alternators. The first two of these major groups are discussed in detail in chapter 14 of *Basic Electricity*, and will not be considered here. The inductor alternator is of considerable importance in missile applications; and a description of its fundamental features is given in the following section. But first, it is desirable to consider the simple equation expressing the frequency of alternators other than the inductor type as given in the basic text:

$$\text{Output frequency} = \frac{\text{R. P. M.} \times \text{Number of poles}}{60 \times 2}. \qquad \text{(Eq. 10–1)}$$

Expressed in words, equation 10–1 says that the frequency in cycles per second generated by the conventional alternator is equal to the rotor speed in revolutions per second (r. p. m. divided by 60) multiplied by the number of PAIRS of poles (number of poles divided by 2).

Also as pointed out in the chapter referenced, the output voltage of the alternator depends upon the number of magnetic lines of flux per pole, the number of conductors per phase, the frequency, and a factor determined by the physical construction of the alternator elements.

THE INDUCTOR ALTERNATOR.—The inductor, or variable-reluctance, alternator differs from other types of machines both in construction and in the principle of operation and output frequency. The rotor of this type of alternator

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carries no windings but consists simply of a toothed, steel wheel. The stator, or stationary element, contains two members—the field and the output coils, or armature. The field may be a permanent magnet or else the windings of an electromagnet. As the rotor revolves, it varies the reluctance of the magnetic circuits carrying the field flux in such a way that the flux path switches or varies in position. The field flux links with the armature coils, and as it changes rapidly, it induces alternating voltage in them.

The basic construction and the flux-switching action can be understood by studying the drawings in figure 10–6. In the center of the assembly is a six-pole rotor, constructed of magnetic material. Surrounding the rotor are two U-shaped, soft-iron field structures with the output coils wound on them. Bridging the gap at the sides are two permanent magnets. It is important to note that the rotor has six poles while the stator has only four; and that the rotor poles do not line up with the field poles simultaneously.

When the rotor is in the position shown in (A) of figure 10–6, a diametrically opposite pair of rotor poles exactly line up with a pair of stator poles. The other pair of stator poles face the rotor slots. In this position, the flux lines take the path indicated in the drawing.

If the rotor is rotated in a clockwise direction to the posi-

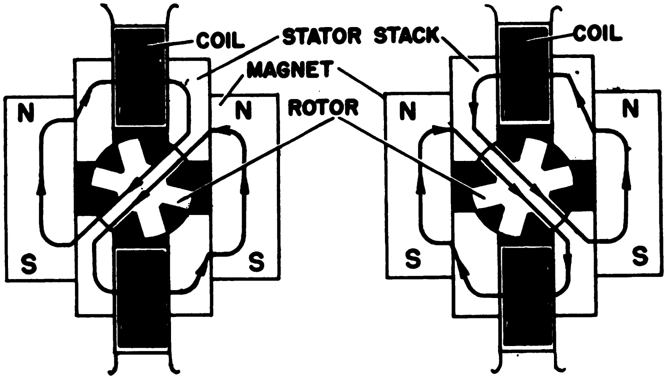

Figure 10–6.—Cross-sectional views of inductor alternator.

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tion shown in (B) of figure 10–6, the stator poles that were formerly carrying flux are then confronted by air gaps and the other pair of stator poles carries the field flux. The flux passes through the outer parts of the stator as before, but its direction is reversed. If the rotor is again rotated clockwise by a small amount, the original flux distribution again exists. Thus it can be seen that as the rotor revolves, the flux in the stator reverses in direction, thereby inducing voltage into the coils wound about the field structures.

An interesting fact concerning the inductor alternator is the relation between the rotor speed in revolutions per second, the number of teeth or poles on the rotor, and the output frequency, expressed by the following formula:

$$\text{Output frequency} = \frac{\text{R. P. M.} \times \text{Number of poles}}{60}. \qquad \text{(Eq. 10–2)}$$

Note that it is the number of poles on the rotor rather than the number of pairs of poles which is a determining factor as in the conventional generator. Thus, for a given rotor speed and a given number of rotor poles, the output frequency is twice that of a conventional machine. Another important fact results from this. The increase in frequency amounts essentially to doubling the output voltage of the generator since a given amount of magnetic flux produces twice the voltage that would be generated by a conventional generator with other factors being the same.

As a result of the frequency relationship, inductor alternators are employed for the generation of alternating voltage of frequencies ranging from 500 to 10,000 cycles per second. Also, because of the comparative simplicity of construction and operation, they are often employed in missile power systems.

Inverters

An inverter is a motor-driven alternator. In its usual form, it is designed to supply high a-c voltage when supplied with a low-voltage, d-c input. Inverters normally furnish current at frequencies either of 400 or 800 cycles per second.

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Both single-phase and three-phase machines are used, with the greater number being of the latter type. Some machines include inductor alternators as the generator section; and these are used to supply power at frequencies up to 10 kilocycles per second.

The physical construction of a conventional inverter is shown in figure 10–7. The unit is composed of a d-c motor and a permanent-magnet alternator assembly. The stators of both the motor and alternator are mounted in a common housing.

The d-c motor is of the shunt-wound, two-pole type, the theory of which is presented in chapter 11 of *Basic Electricity*, NavPers 10086. Direct current is applied to run the motor by means of the brushes and commutator. After flowing through the motor armature, the current is grounded

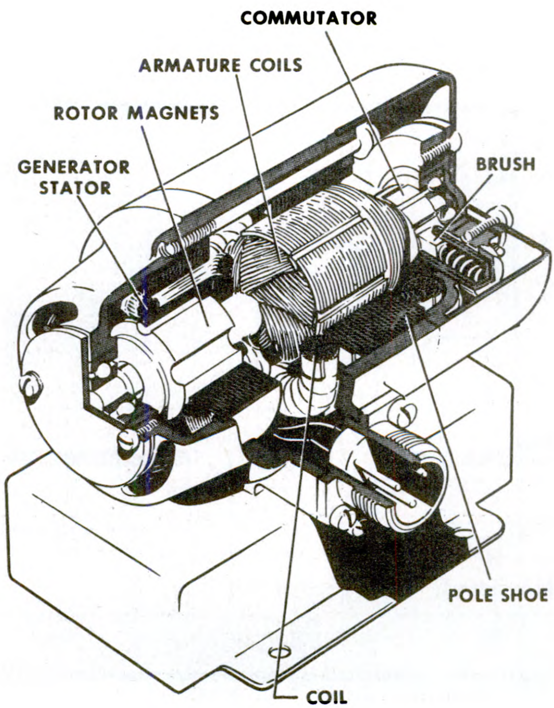

Figure 10–7.—Cutaway view of inverter.

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through the frame. The shunt windings are connected across the armature to provide field excitation and consist of two interconnected coils, each of which is placed around a laminated pole shoe secured to the inside of the frame. The armature coils are wound to form a two-pole, lap-wound armature, the details of which are discussed in the basic text.

The alternator section of the inverter shown (fig. 10–7) consists of a revolving-field, three-phase generator connected in "wye" as indicated in figure 10–8, which is a simplified wiring diagram of the machine.

A three-wire, polarized receptacle is provided (fig. 10–8) so that the proper connections can be made. The three-phase output is taken from terminals A and C at the receptacle, while the third phase is grounded through the frame. The machine supplies 400-cycle alternating current from an input of 25- to 30-volt d. c.

Another motor-driven alternator, or inverter, representative of the type designed specifically for missile use is illus-

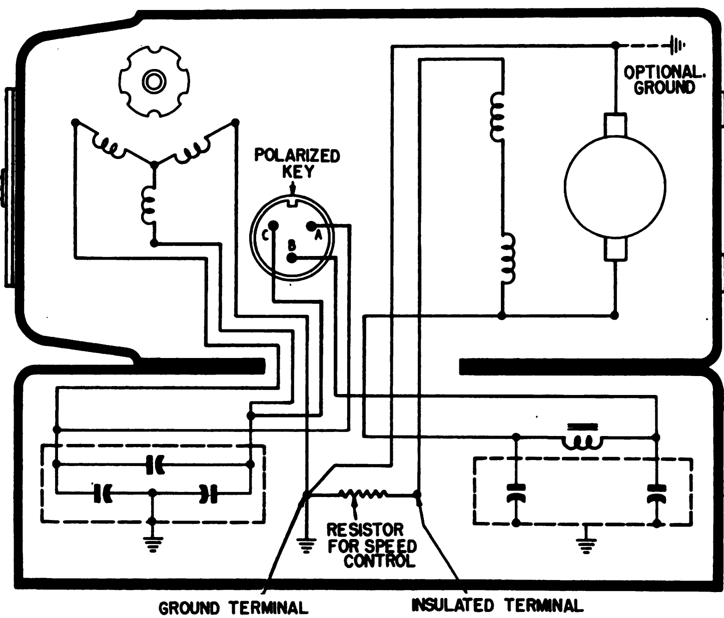

Figure 10–8.—Wiring diagram of inverter.

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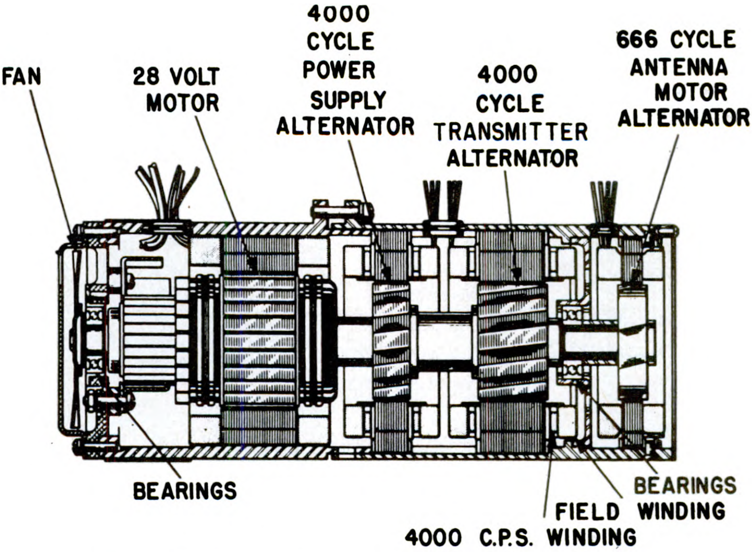

Figure 10–9.—Cross-sectional view of three-phase inverter.

trated in figure 10–9. In addition to the motor, this machine contains two inductor type alternators and one permanent-magnet alternator, all mounted in one housing. Physically the inverter is about 4 inches in diameter and 10 inches long. It will supply approximately 900 watts of usable power.

The armature of the motor and the rotors of the three alternators are mounted on one shaft. The motor is driven at a speed of 20,000 r. p. m. with an applied voltage of 28 volts supplied by the battery.

Each rotor of the two inductor alternators is composed ot 12 poles; so that according to equation 10–2, the output has a frequency of 4,000 cycles per second. The rotor of the permanent-magnet alternator has four poles, so that by equation 10–1, the output frequency is 666 c. p. s.

Dynamotors

A dynamotor is a combination of a d-c motor and a d-c generator in which the two units are mounted as a single machine and operate with a common magnetic field. In construction, the machine may have either two armatures

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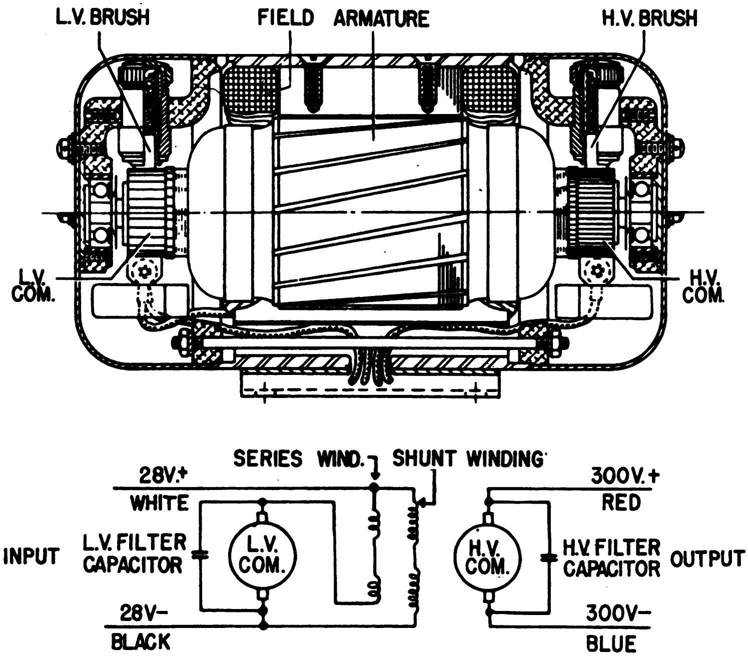

Figure 10–10.—Cross-sectional view and wiring diagram of typical dynamotor.

on one shaft or one armature composed of two separate sets of windings, each of which is provided with a commutator. Dynamotors have less power capability than inverters of comparable size and are frequently used where relatively small amounts of current must be supplied the load elements at high d-c voltages. They usually are light in weight and are frequently used in mobile electronic equipment. Dynamotors have been constructed to give d-c voltages as high as 2,000 volts; but in these, the problems of insulation and commutation are important considerations.

In the dynamotor illustrated in figure 10–10, current is supplied through the low-voltage commutator and flows in the low-voltage winding of the armature. The d-c source also supplies current for the field coils to produce the field flux. Reaction of the field with the magnetic flux in the low-voltage motor winding causes rotation of the armature.

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The generator winding of the armature has a voltage induced in it since it is rotating in the common magnetic flux produced by the field coils. Since the generator winding has a much larger number of turns than the low-voltage winding, the voltage induced in the generator section is greater than the applied voltage roughly in proportion to the turns ratio. When rectified by the generator commutator, the output then consists of unidirectional current at high voltage, which is applied to the external load circuit through the generator brushes.

PRIME MOVERS FOR ROTATING EQUIPMENT

No single power supply system is compatible with all types of missiles since each has its own particular power requirements and other characteristics which determine the suitable methods of developing the power. This is true not only of the secondary equipment employed, such as vibrators and alternators, but also with regard to the type of prime mover used to drive electric generators. Several types of prime movers are used in missiles, the principal kinds being the following: (1) d-c motors powered by batteries; (2) hydraulic motors which are geared to the driven alternators; (3) turbines driven either by compressed air or by gas from a burning chemical propellant; (4) airscrews. An example of the d-c motor used as a prime mover is given in the inverter discussed in a previous section and also the dynamotor described in the section immediately preceding this one. The remaining devices are described in the following pages.

Systems Driven by Hydraulic Motors

In missiles containing closed hydraulic systems and in those with open systems of sufficient capacity, a hydraulic motor may be used as a prime mover to drive electric machinery. A simplified block diagram of such a system is shown in figure 10–11. Unlike the power supply based on inverters or dynamotors, the hydraulically powered supply requires no batteries.

The system shown in figure 10–11 is a closed type in which high-pressure hydraulic fluid is delivered by a pump to a

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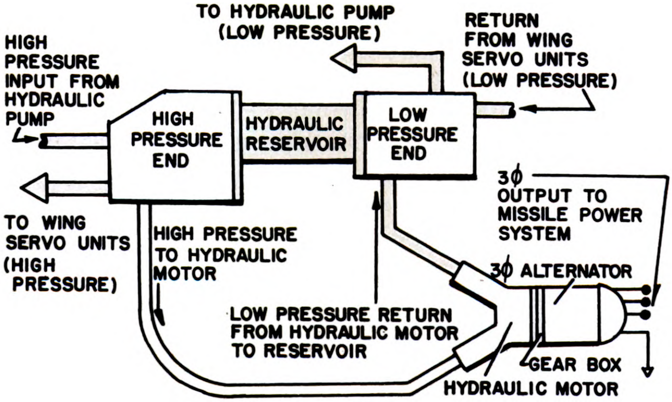

Figure 10–11.—Block diagram of electrical system with hydraulic drive.

RESERVOIR. From the high-pressure end of the reservoir, connections are made both to the wing servo units and to the inlet port of the hydraulic motor. The motor provides the mechanical energy needed to rotate the rotor of the three-phase alternator, which supplies the electrical power expended in the missile units.

A gearbox provides a mechanical connection between the motor and the alternator. In most cases, the gear ratio is such that the speed of the motor shaft is stepped up in order to drive the alternator at its rated r. p. m.

A typical hydraulic motor used as a prime mover for an

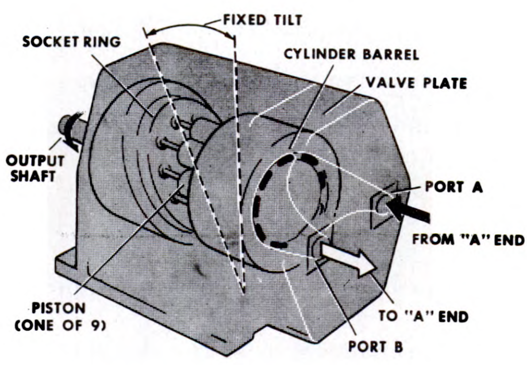

Figure 10–12.—Hydraulic motor.

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electrical supply system is illustrated in figure 10–12. Similar in basic construction to the axial piston hydraulic pump (discussed in *Basic Hydraulics*, NavPers 16193, chapter 12), the motor receives hydraulic fluid under pressure and converts the energy into mechanical rotation. The principle of operation is similar to that of the pump except that the motor is moved by the hydraulic pressure rather than being a mechanism for producing pressure. Referring to figure 10–12, fluid entering the inlet port forces the pistons successively down the cylinder block against the tilted plate, thereby causing the plate and cylinder block to revolve. On the return stroke, the piston discharges the fluid from the outlet port into the low-pressure side of the reservoir.

Turbine-Driven Systems

The hydraulic motor described above is an example of a RECIPROCATING device in that the back-and-forth motion of the pistons is converted into rotary motion. The turbine is an engine of a fundamentally different kind, and is an example of a rotary device. By definition, a turbine is a rotary engine actuated by the reaction of fluid, either liquid or gaseous, flowing at high pressure.

Small turbines have been designed to drive high-speed alternators in missile power systems. In these engines, the principal component, the turbine rotor, may be one of two basic types. Examples of each are shown in figure 10–13. In (A) of the figure, showing a bucket-type rotor, the wheel is a solid piece of steel having semicircular recesses, or

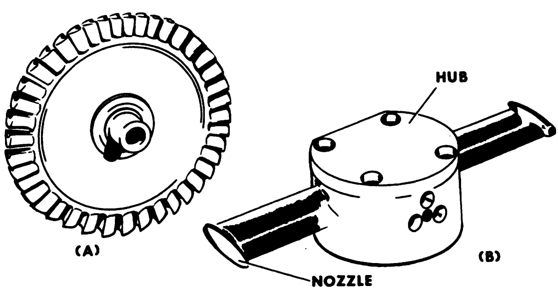

Figure 10–13.—Turbine wheels. (A) Bucket type; (B) pinwheel type.

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buckets, milled into the outer rim. The wheel runs near a stationary housing into which stationary nozzles are set; and these conduct high-pressure gases into the turbine buckets. When the gas impinges upon the buckets, it is reversed in direction and passes into a semicircular reversing chamber mounted in the housing, whereupon it is returned to the wheel. This process may be repeated several times before the gas is conducted to the exhaust port, thereby giving a multiple-stage effect so as to utilize as much of the available kinetic energy of the flowing gas as possible. Turbines of this type are usually powered by the gases derived from burning solid propellants.

A turbine wheel of the pinwheel type is shown in (B) of figure 10–13. The rotor element consists of a hub from which extend two hollow arms. At the tip of each arm, a small nozzle is mounted with the opening directed in such a way that when the gas is released through the hollow arms, the resulting reaction imparts rotary motion to the assembly. Thrust is produced by the escaping gas in the same way that it is produced by a jet aircraft engine with the result the rotor assembly turns at high speed, a typical rotary rate being 20,000 revolutions per minute. At this speed, the velocity of the arm tips is in the order of 400 to 500 feet per second.

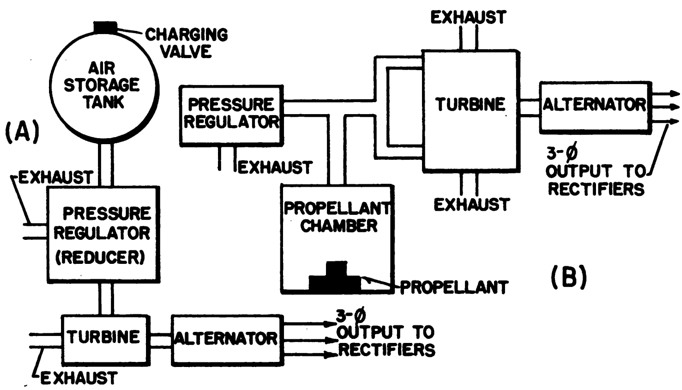

Figure 10–14.—Block diagram of turbine-driven alternators. (A) Compressed-air type; (B) solid-propellant type.

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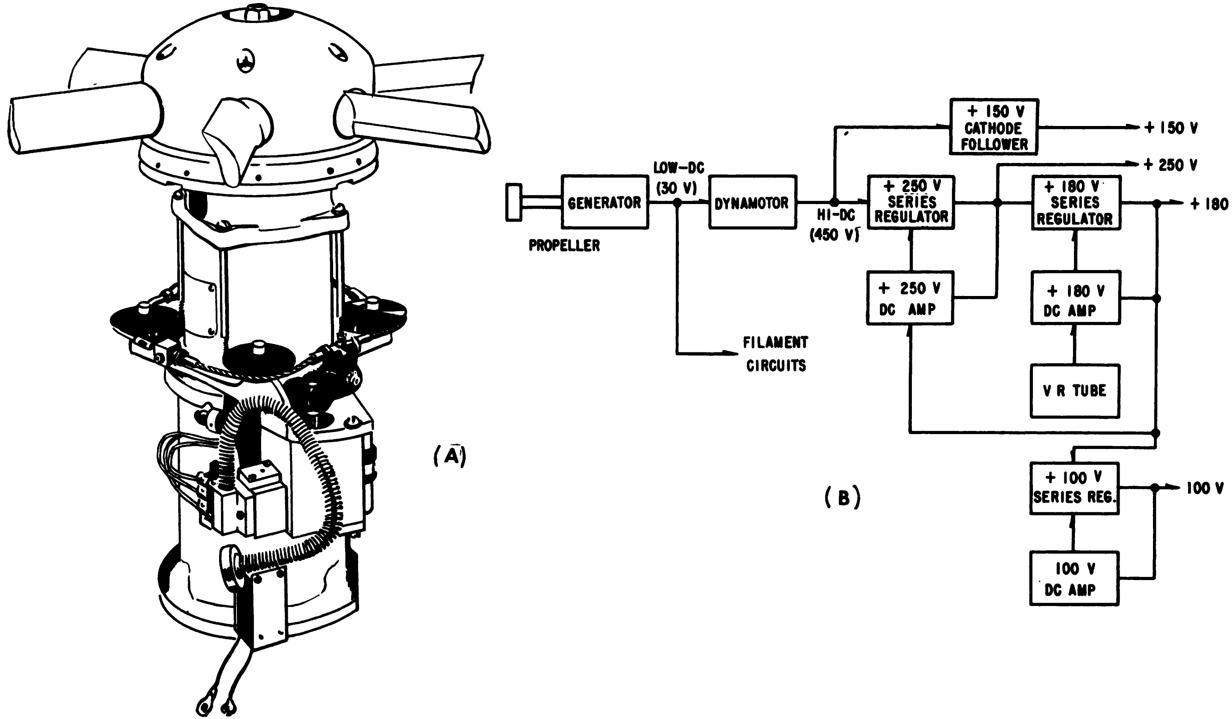

Figure 10–15.—(A) Propeller-driven generator; (B) block diagram of associated power equipment.

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Energy to drive the turbine is derived in missile applications in one of two ways, which are illustrated in figure 10–14. In (A) of the figure, air is stored at high pressure in a small metal tank. It is released to a PRESSURE REDUCER (or regulator) which lowers the pressure of the air delivered to the turbine to approximately 300 to 400 pounds per square inch. Turbines operating with air tanks usually employ pinwheel rotors, the performance of which depends upon the operating pressure, the arm length, the shape of the arm, the nozzle size, and the speed of the rotor. Typical arm lengths are four to six inches and typical speeds up to about 25,000 r. p. m. A turbine of this type is capable of developing up to two horsepower.

In (B) of figure 10–14, a turbine system is illustrated in which the hot gas liberated by a burning propellant supplies the kinetic energy used to run the turbine and hence the alternator. In turbines of this type, bucket wheels are usually employed. The chemical propellant is ignited in an enclosed chamber and the hot gases resulting from combustion supply the necessary high-pressure energy. Typical operating temperatures of the gas at the turbine inlet port are in the order of 2,000° F.

AIRSCREW-DRIVEN GENERATORS

In certain kinds of missiles, particularly in the air-to-surface class, the airframe configuration allows a propeller to be mounted so that it projects into the airstream around the missile. The propeller is mechanically connected to an armature of a d-c generator; and when caused to rotate by the airstream, it drives the rotor of a generator—usually a low-voltage, d-c machine.

In figure 10–15 is shown a generator designed for use in a system of this type. The low-voltage d. c. produced by the generator is used for the filaments of the electron tubes and as the primary voltage to operate a dynamotor. The high-voltage, d-c output of the dynamotor is then regulated by electronic series regulators and applied to the electronic circuits of the missile.

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QUIZ

1. A major determining factor in the selection of a primary power source for a guided missile is the
   a. type of propulsion employed
   b. type of guidance employed
   c. fuzing method
   d. navigation course flown by the missile
2. A basic requirement of a missile power supply is
   a. fast actuation time
   b. long active life
   c. short storage life
   d. complex design
3. Electronic-component loads are defined as those which
   a. consist of filaments of electron tubes
   b. include gyros and accelerometers
   c. are supplied by the rectifier circuits
   d. consist of the control elements of the servo valves
4. The two basic types of missile power supplies are
   a. a. c. and d. c.
   b. chemical and battery
   c. generators and motors
   d. static and dynamic
5. The machine supplying the rotary motion to be converted to electrical energy is called a/an
   a. dynamotor
   b. prime mover
   c. alternator
   d. generator
6. A battery-operated power supply is capable of supplying a-c voltages by using
   a. magnetic amplifiers
   b. dynamotors
   c. vibrator and transformer
   d. a transformer and rectifier
7. An advantage of the dynamic power supply is its
   a. ability to supply more power
   b. voltage stability
   c. simplicity of design
   d. ease of servicing

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8. Telemetering equipment usually uses a/an __________ power supply.
   a. inverter
   b. dynamotor
   c. d-c generator
   d. battery

9. The type of battery cells generally favored for missile use is
   a. silver-zinc
   b. nickel-cadmium
   c. lead-acid
   d. zinc-acid

10. A characteristic of the silver-zinc battery after activation is its
   a. high output voltage
   b. short shelf life
   c. large voltage variations
   d. low current capabilities

11. Batteries are heated to
   a. prevent freezing of the electrolyte
   b. insure proper operation of the activator
   c. decrease time required for proper voltage stabilization
   d. decrease the discharge rate

12. The purpose of a vibrator in a vibrator power supply is to
   a. step up the voltage
   b. step up the current
   c. convert a. c. to d. c.
   d. convert d. c. to a fluctuating potential

13. The buffer capacitor in a vibrator power supply
   a. prevents arcing of the contacts
   b. filters the input potential
   c. bypasses the rectifier
   d. is part of the "pi" section filter

14. The basic principle upon which both a-c and d-c generators depend is
   a. mutual inductance
   b. electromagnetic induction
   c. magnetic attraction
   d. overcoupling

15. The primary difference between a-c and d-c generators is in the
   a. construction of the rotor
   b. construction of the stator
   c. method of taking the induced voltage from the coil
   d. method of moving the rotor

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16. A commutator is the device used in a d-c generator to
    a. provide excitation of the field magnet
    b. produce an e. m. f. to be delivered to the load
    c. convert mechanical energy into electrical energy
    d. convert the a. c. generated in the moving coil into a d. c. through the load
17. The a-c generator uses __________ to connect the generated voltage to the load.
    a. sliprings
    b. commutators
    c. coils
    d. capacitors
18. One determining factor of the output frequency of an alternator is the
    a. number of conductors in the armature
    b. number of poles in the field
    c. amount of voltage applied to the field
    d. amount of current flowing in the armature
19. An inverter is referred to as a
    a. motor
    b. dynamotor
    c. motor-driven alternator
    d. voltage regulator
20. The rotor of an inductor alternator is driven at 20,000 r. p. m.; the rotor is composed of 12 poles; the output frequency is
    a. 4,000 c. p. s.
    b. 5,000 c. p. s.
    c. 6,000 c. p. s.
    d. 8,000 c. p. s.
21. A dynamotor is a/an
    a. a-c driven motor with d-c output
    b. combination of d-c motor and d-c generator
    c. d-c driven motor with an a-c output
    d. belt-driven generator
22. Dynamotors can be used for
    a. low current, high voltage
    b. high current, low voltage
    c. high current, high voltage
    d. higher power as compared with inverters
23. The prime mover of a dynamotor is a
    a. hydraulic motor
    b. gas-driven turbine
    c. d-c motor
    d. battery

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24. Pressure from the high-pressure air tank through the regulator to drive the turbine is approximately
    a. 200 to 300 p. s. i.
    b. 300 to 400 p. s. i.
    c. 400 to 500 p. s. i.
    d. 3,000 to 4,000 p. s. i.

25. Turbines operating with air tanks are capable of developing up to
    a. 4 horsepower
    b. 3 horsepower
    c. 5 horsepower
    d. 2 horsepower

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CHAPTER 11

INTRODUCTION TO MISSILE TELEMETERING

When any new device is being developed, it must be given an exhaustive series of tests which reveals its operating characteristics and serves as the basis of evaluation. With most devices, the conditions are such that one or more human observers can study the action close at hand and measure numerous quantities while the apparatus is in operation. A new type of airplane is repeatedly flown under all sorts of conditions by a skilled test pilot. And each flight provides first-hand information as well as information derived from instruments and recorded for later study. A new engine for an automobile is first placed on a test stand; it is run for long periods of time, during which it is observed closely and numerous measurements are made to determine its capabilities. Later it can be installed in an automobile and tested for as long as may be required.

One of the important problems in missile development is that the missile cannot be flight tested by a human pilot. Also, in most cases, once the missile is fired it is gone forever, being reduced to junk upon striking the earth or sinking beneath the surface when it comes down at sea. (In the development of large, surface-launched missiles, the test vehicle is sometimes equipped with landing gear and can be brought to earth without destruction; but this is rarely if ever the case with smaller, air-launched weapons.) As a result, the missile designers have of necessity developed other methods for deriving test data pertaining to these single-flight birds.

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INITIAL TESTING

The initial tests of a new missile system are often made on a flight simulator, which is a special type of computer. The performance characteristics of the individual components of the proposed missile are set into the simulator in the form of dial settings (or equivalents); and the results come out as curves traced on graph paper. In this way, a simulated "flight" takes only a few seconds and costs almost nothing compared with an actual flight. After a simulated flight, adjustments can be made to determine whether the performance can be improved by altering the control surfaces, by changes in the control system, and so on. If all the necessary information had to be derived by actual test, the expense would be prohibitive since the testing of the numerous individual sections or components by actual flight would cost a new missile for each separate item. After flight simulation is completed, the new missile can then be constructed in accordance with the best results obtained from the simulator; and actual flight testing can begin.

Electronic and mechanical components react differently under the various conditions of missile operation. Results gained when testing the missile on the ground may be very different from the results obtained when firing the missile at an altitude of 30,000 feet. Temperatures, pressures, and accelerations encountered at the higher altitudes may change the operation of the missile materially. In order that the operation of the overall system might be made known under actual firing conditions, specialized TELEMETERING equipment was designed and produced for missile use.

REQUIREMENTS OF MISSILE TELEMETERING EQUIPMENT

Telemetering is a word of Greek origin, meaning "measurement from a distance." Both the term and the processes it signifies have been used in industry and elsewhere for a number of years. In many industrial applications, various kinds of data are often transmitted over wire links. Radio telemetering has also been in use since the midthirties, especially for sending weather data gathered by balloon-

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supported instruments and emitted by radio transmitters. The principal element of this kind of equipment is called RADIOSONDE, which is still one of the most important tools in the aerographer's job, particularly in that part of it which pertains to weather forecasting.

Like radiosonde, missile telemetering systems operate by radio. These systems permit the measurement and study of missile performance from a remote point. They are usually designed to carry out the following major processes or functions: conversion of the quantities to be studied into electrical signals; transmission of the signals from the missile transmitter to a receiving station, located either in an airplane or on the ground; reception of the signals and decoding of the various data; presentation of the data in visual form and recording of them in permanent records.

Since a great amount of varied information is required during the separate stages of a missile test program, the primary requirement of a missile telemetering system is the ability to gather, transmit, and process a large amount of data in a short period of time. The types of information usually required include (1) changes in attitude in pitch, yaw, and roll; (2) airspeed; (3) altitude; (4) various components of acceleration; (5) ambient conditions such as pressure, temperature, and humidity; (6) operation of the control equipment, such as the receiver, autopilot, hydraulic servos, the displacement of the control surfaces, and the operation of the homing or target-seeking equipment; (7) propulsion information, such as temperature and pressure of the rocket assembly; (8) ordnance functions, such as fuze-arming time; (9) the operation of the electrical system; and (10) data required for the coordinated operation of the telemetering equipment itself, such as reference voltages used for calibration, time marks, and signals which permit the synchronizing of the data recorded by several receivers located along the flight path.

The receiving equipment is designed to accept all the information provided by the transmitter in the missile, to demodulate the separate signal channels, and to decode the resultants for presentation to the recording section. Proper

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recording of the information derived is the final step in the process. The permanent records are made by various means: by magnetic-tape recorders, by pen recording equipment, and on photographic film. In photographic recording, both movie and still cameras are employed.

Radio transmitting and receiving equipment of the frequency-modulated and of the pulse types are used in missile telemetering. The principal features of the former type are considered first, the following section being devoted to a description of the F–M/F–M system.

THE F–M/F–M TELEMETERING SYSTEM

The F–M/F–M telemetering system employs the basic techniques of frequency modulation and can be used to transmit simultaneously large quantities of missile data. The missile-borne portion of the system includes a number of frequency-modulated oscillators, the combined outputs of which are fed into a frequency-modulated, very high-frequency transmitter. Each separate oscillator produces a signal called a SUBCARRIER, the frequency of which is modulated in accordance with one of the missile functions to be monitored. The number of subcarrier oscillators (and hence, the number of missile functions telemetered) may be as high as 18.

The essential elements of both the missile equipment and

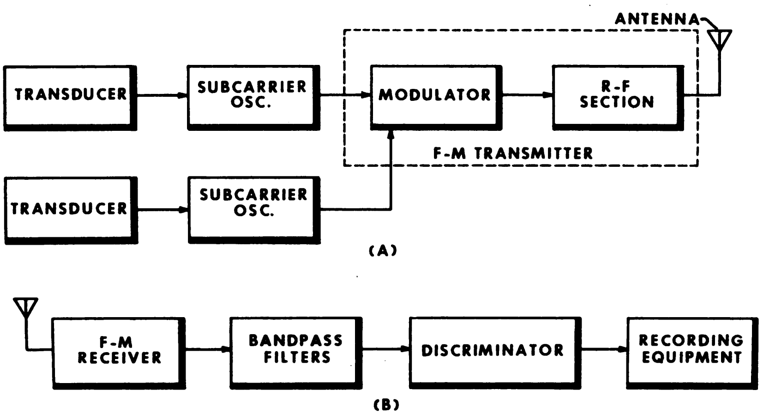

Figure 11–1.—Simplified block diagram of an F–M/F–M system.

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the receiving section of the overall system are indicated in the block diagram in figure 11–1. In (A) of the figure, representing the components carried in the missile, only two subcarrier oscillators are shown for simplicity; however, in most installations the number of oscillators included is much greater. The subcarrier oscillators operate on different center frequencies so that each provides a separate signal channel. Each oscillator is frequency modulated by means of a pickup device, called a TRANSDUCER. One transducer is used for each signal channel, the function of the device being to convert the quantity to be measured into a form suitable for modulating the associated oscillator.

The various subcarrier signals are applied to the MODULATOR which in turn modulates the output of a crystal controlled oscillator in the radio-frequency section of the transmitter. The resulting signal is multiplied in frequency up to the value assigned for the carrier wave and is then applied to the antenna for transmission to the receiving station. The carrier frequencies allocated for telemetering purposes are included in a band ranging from 216 megacycles to 235 megacycles.

As indicated in figure 11–1, the transmitted carrier wave is picked up at the receiving station by an f-m RECEIVER. After considerable amplification, the subcarrier signals are detected and then separated into separate channels by means of BANDPASS FILTERS. Each signal channel contains a DISCRIMINATOR, which converts the frequency variations present in the subcarrier into audio-frequency variations, the amplitudes of which are proportional to the value of the corresponding quantity measured in the missile. The a-f signals developed in the various signal channels are then recorded for data reduction and evaluation.

Subcarrier Frequencies

The subcarrier oscillators used in the telemetering transmitter generate comparatively low-frequency signals situated in the bands given in table 11–1. Eighteen standard bands are allocated for telemetering subcarrier use. In addition, five optional bands are provided for special pur-

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poses which require a greater value of allowable frequency deviation than that established for the standard bands. As indicated in the table, the center frequencies about which the subcarriers are modulated range from 400 c. p. s. to 70 kilocycles. The permissible frequency deviation in the standard bands is plus or minus 7.5 percent and 15 percent in the optional bands. The intelligence frequencies, which represent the quantities to be telemetered, range in typical value from 6 to 30 c. p. s. in the lowest band and from 2,100 to 10,500 c. p. s. in the highest.

Table 11–1.—Subcarrier oscillator frequency bands

Band	Lower limit (c. p. s.)	Center frequency (c. p. s.)	Upper limit (c. p. s.)	Typical intelligence frequency (c. p. s.)	Maximum intelligence frequency (c. p. s.)	Frequency deviation (percent)
1	370	400	430	6	30	±7. 5
2	518	560	602	8	42	±7. 5
3	675	730	785	11	55	±7. 5
4	888	960	1, 032	14	72	±7. 5
5	1, 202	1, 300	1, 398	20	98	±7. 5
6	1, 572	1, 700	1, 828	25	128	±7. 5
7	2, 127	2, 300	2, 473	35	173	±7. 5
8	2, 775	3, 000	3, 225	45	225	±7. 5
9	3, 607	3, 900	4, 193	60	293	±7. 5
10	4, 995	5, 400	5, 805	80	405	±7. 5
11	6, 799	7, 350	7, 901	110	551	±7. 5
12	9, 712	10, 500	11, 288	160	788	±7. 5
13	13, 412	14, 500	15, 588	220	1, 088	±7. 5
14	20, 350	22, 000	23, 650	330	1, 650	±7. 5
15	27, 750	30, 000	32, 250	450	2, 250	±7. 5
16	37, 000	40, 000	43, 000	600	3, 000	±7. 5
17	48, 560	52, 500	56, 440	790	3, 940	±7. 5
18	64, 750	70, 000	75, 250	1, 050	5, 250	±7. 5
Optional bands:						
A	18, 700	22, 000	25, 300	660	3, 300	±15
B	25, 500	30, 000	34, 500	900	4, 500	±15
C	34, 000	40, 000	46, 000	1, 200	6, 000	±15
D	44, 620	52, 500	60, 380	1, 600	7, 880	±15
E	59, 500	70, 000	80, 500	2, 100	10, 500	±15

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TRANSMITTING EQUIPMENT

Input Transducers

As indicated in figure 11–1, the telemetering process originates in the airborne equipment where the missile functions are detected and measured by the input transducers. By definition, a transducer is any device which is used to convert energy in one system into energy of a form suitable for use in another system. In missile telemetering applications, the input transducers commonly employed include VARIABLE-RELUCTANCE, VARIABLE-INDUCTANCE, and VARIABLE-RESISTANCE units. Because of the required compactness of missile equipment, the transducers are usually specially designed for the particular system and are usually mounted as integral parts of the subcarrier oscillator circuitry. As parts of the subcarrier oscillators in an F–M/F–M system, they operate by converting the missile functions into audio-frequency signals which modulate the output of the oscillator in frequency.

An example of the variable-reluctance transducer is the accelerometer, the theory of which is discussed in chapter 8 of this course. In addition to acceleration, missile quantities frequently measured by variable-reluctance units include ambient pressure, velocity, motions of servo linkages, and positions of control surfaces.

A typical member of the variable-inductance class of transducers is the saturable reactor, which is often used to measure missile quantities such as critical power-supply voltages or the currents flowing in certain tubes in the electronic circuits. The saturable reactor designed for use as a transducer consists of a laminated, magnetically saturable core upon which is wound an inductance coil, a control coil, and a biasing coil. As the current in the control winding is changed, the magnetization of the core changes with the result that the inductance of the principal coil is varied correspondingly. When connected so as to form a part of the tank circuit of an oscillator, the inductance coil by its variations can control within limits, the frequency of the oscillator. The saturable reactor is a power-consuming device and is not

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desirable for measuring missile functions represented by voltages which are developed in high-impedance sources such as AGC voltages in missile receivers.

A typical example of a variable-resistance telemetering pickup is shown in figure 11–2. The potentiometer, serving as the transducer, and the oscillator which it controls, make up a subcarrier signal channel for monitoring the position of a missile wing. The slider of the potentiometer is mechanically coupled to the wing so that a variable voltage is picked off and applied to a control tube which forms part of the oscillator circuit. For each position of the wing there is a corresponding value of voltage applied to the control tube, which adjusts the output frequency of the circuit in accordance with the instantaneous positions of the wing.

Impressed across the potentiometer (fig. 11–2) is a regulated, d-c potential of 50 volts. When the wing is in the center, or zero position, the potentiometer arm is also at the center position where it applies 25 volts to the control tube. This voltage serves as a bias for the control tube which causes the output signal of the oscillator to be situated at 1.7 kilocycles, the center value of band 6 (table 11–1). As the wing moves in response to the missile control system, the slider of the potentiometer moves also and readjusts the control-tube bias. As a result, the output frequency is varied within the limits of 1,572 and 1,828 c. p. s.

The oscillator employed in the system shown in figure 11–2

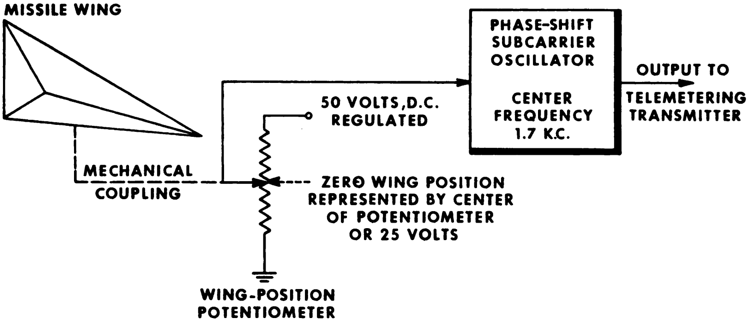

Figure 11–2.—Wing-position telemetering device.

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is of the phase-shift type, a basic circuit often used in telemetering applications because of the ease with which its frequency can be varied by means of a biasing voltage. The operation of the circuit is explained in detail in the following section.

Subcarrier Oscillators

Two basic circuits are widely used as subcarrier oscillators in f-m telemetering systems. One is the phase-shift circuit mentioned in the preceding section; the other is the Hartley oscillator, the theory of which is discussed in chapter 7 of *Basic Electronics*, NavPers 10087. The application of both types in a representative missile telemetering transmitter, together with typical frequency values employed in the two types is indicated in the block diagram shown in figure 11–3. The components shown comprise a transmitting system capable of providing 10-channel telemetering.

THE HARTLEY CIRCUIT.—The Hartley oscillator, when used as a subcarrier generator, is most frequently equipped with a variable-reluctance transducer. An example of this arrangement is shown in schematic form in figure 11–4 in which the transducer is an accelerometer. In such applications, the accelerometer is usually of the E-coil type and is connected as the inductance portion of the tuning, or tank, circuit of the oscillator.

The circuit shown (fig. 11–4) might be employed for telemetering the values of one component of missile acceleration. The E-coil and mu-metal pad of the accelerometer form a variable-reluctance pickoff, the sensitive element of which responds to acceleration in one of the missile axes. Changes in the air gap of the accelerometer result in corresponding changes in the reluctance of the magnetic path, with a resulting change in the inductance of the winding connected in the oscillator tuning circuit. In this way, the output of the oscillator is frequency modulated by amounts proportional to the missile accelerations to which the transducer is sensitive.

PHASE-SHIFT OSCILLATORS.—The operation of the phase-

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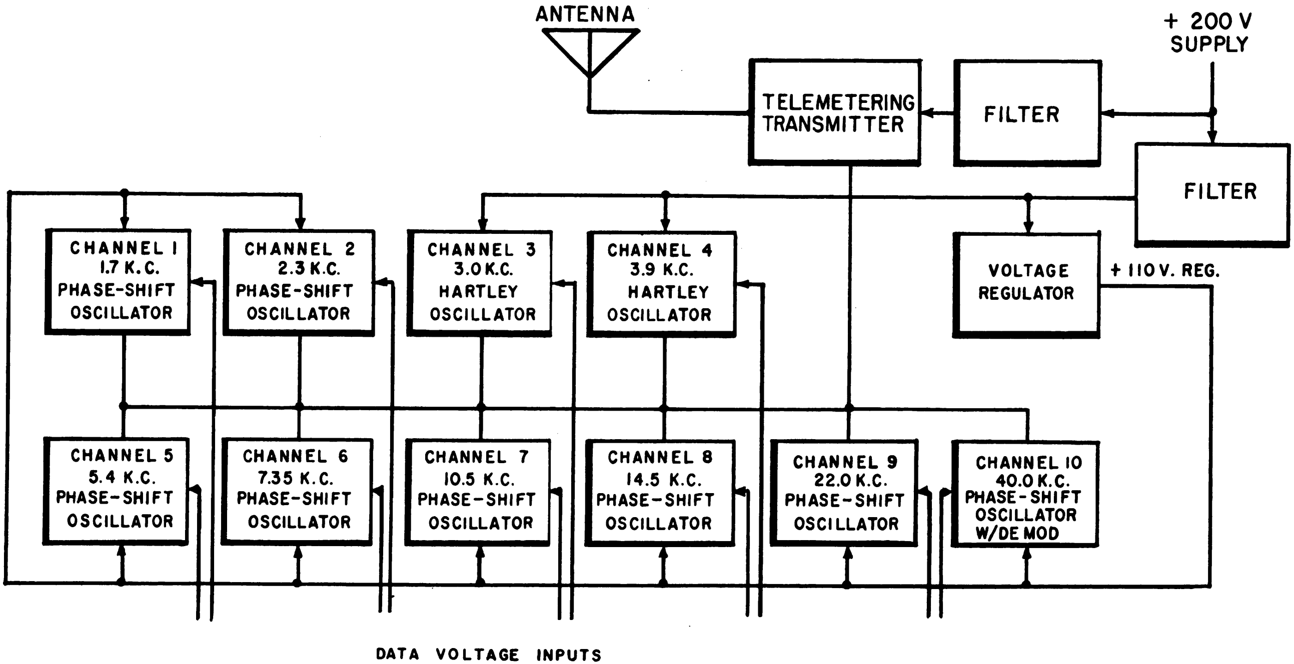

Figure 11-3.—Block diagram of 10-channel transmitting equipment.

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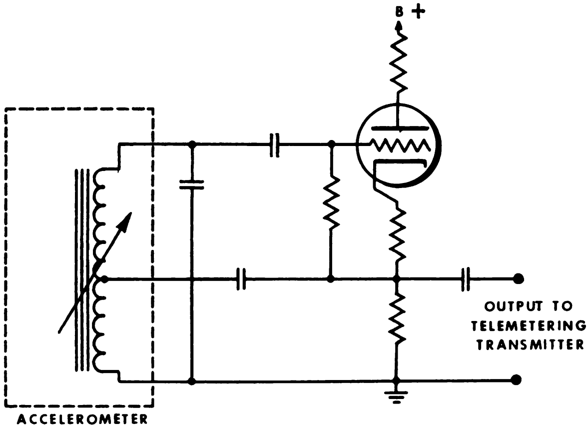

Figure 11–4.—Hartley oscillator with accelerometer transducer.

shift oscillator is based on the following facts concerning electronic amplifiers. If the output voltage of a single-stage amplifier is fed back to the input through a frequency-sensitive network, the circuit will oscillate. The frequency of oscillation is that value at which the network shifts the phase of the feedback voltage by 180 electrical degrees with respect to the output voltage. The oscillation will be sustained if the gain of the amplifier is great enough to overcome the losses of the coupling network.

A simplified schematic diagram of an oscillator which operates on these principles is shown in (A) of figure 11–5. The circuit contains a control tube to provide a means of varying the frequency of the output signal over a range sufficiently wide for f-m telemetering; and in this form, the oscillator is suitable for use in a subcarrier channel of an F–M/F–M system. A vector diagram illustrating the phase relations upon which frequency control depends is shown in (B) of the figure.

The oscillator employs a three-section, R–C network to provide the phase displacement necessary for oscillation. The network is composed of the sections R_1–C_1, R_2–C_2, and R_3–C_3. These, together with V–2, a cathode-follower tube, make up the feedback loop through which voltage variations are coupled from the plate of V–1, the oscillator tube, back

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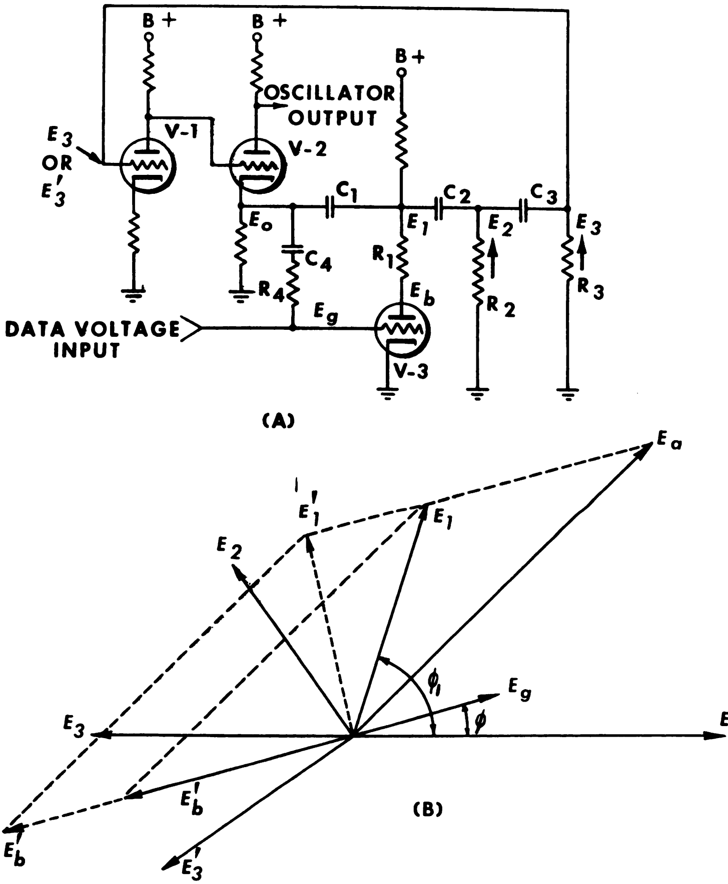

Figure 11–5.—(A) Schematic diagram of a phase-shift oscillator; (B) vector diagram.

to the grid. V–2 serves to match the impedance of the network to the oscillator tube and to couple the signal to the control tube, V–3. The cathode-follower stage also provides a convenient element from which the output signal of the circuit can be taken. When placed in operation, the circuit generates oscillations at the frequency at which the R–C network provides the necessary 180-degree phase shift.

The control tube, V–3, varies the frequency of the output

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signal in accordance with the data voltage applied to the grid. The plate circuit of the tube is a part of the input section of the R–C network; and the tube action determines the phase shift produced in this section, thus governing the frequency at which the circuit can oscillate. The change in phase angle introduced by the control tube is shown in (B) of figure 11–5. This method of representing phase relationships is based on the discussions given in chapters 12 and 13, *Basic Electricity*, NavPers 10086.

The vector labeled E_o symbolizes the voltage at the output of the cathode follower. This voltage is coupled both to the R–C network and also to the grid of the control tube through the combination R_4–C_4 which produces a phase shift of ϕ degrees (fig. 11–5). The output, or plate voltage, of V–3 is an amplified voltage, E_b, which is 180 degrees out of phase with the grid voltage. The voltage, E_a, appears across R_1 and results from coupling the output of the cathode follower through C_1. The vector sum of E_a and E_o is E_1, the resultant voltage appearing at the first R–C section. This voltage produces voltages E_2 and E_3 at the second and third sections of the network, respectively. The voltage E_3 is applied to the input of the oscillator tube in the proper phase relation to cause oscillation.

Any increase in the data voltage causes the plate voltage of V–3 to change from E'_b to E_b as shown in (B) of figure 11–5. The voltage E_a remains substantially constant so that E_1 now shifts to E'_1. Voltages E_2 and E_3 depend upon E_1 and shift in phase in accordance with it. The voltage now fed back to the grid of the oscillator tube is no longer in the proper phase to sustain oscillation at the previous frequency. As a result, the output signal is changed to a new frequency at which the total phase shift of the network is once more 180 degrees. The new frequency is then a measure of the data signal voltage applied to the control tube.

The Telemetering Transmitter

As indicated in figure 11–3, the output signals from all the subcarrier oscillators in the F–M/F–M system are fed to a common point, the input of the telemetering transmitter.

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The components of a transmitter of the type employed in the system are shown in a block diagram in figure 11–6. The carrier frequencies of telemetering transmitters are situated in the band extending from 216 to 235 megacycles. As indicated in the figure, the signal from which the carrier is developed originates in a crystal oscillator operating at a comparatively low frequency, a typical value being that shown in the figure, or 6.096 mc. After the output of the crystal oscillator is modulated in frequency by the modulator stage, the resulting voltage, which contains all the telemetering information contributed by the subcarrier channels, is multiplied up to the assigned carrier-frequency value. The frequency multiplication is accomplished by a series of multiplier stages containing both doublers and triplers.

For a discussion of the process of phase modulation employed in the transmitter (fig. 11–6), the trainee is referred to *Basic Electronics*, NavPers 10087, chapter 8. In the same text he will also find information on an f-m transmitter essentially similar to the telemetering equipment shown above. The discussion in chapter 9 contains a generalized block diagram, a schematic diagram, and detailed description of the operation of the various stages including the function of the frequency multipliers.

Missile telemetering transmitters differ from the f-m equipment explained in the companion text principally in physical

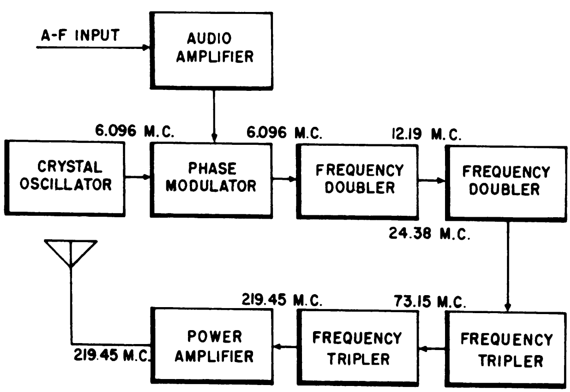

Figure 11–6.—Block diagram of F–M/F–M telemetering transmitter.

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form since the missile units must be designed for maximum compactness and light weight. The missile-borne telemetering antenna also differs in construction from conventional f-m antennas because it must conform to the aerodynamics of the missile.

F-M/F-M Receiving Equipment

Figure 11-7 is a block diagram showing the principal components of a 10-channel receiving station that supplements the transmitting equipment described above. The basic units include a specialized antenna system; an f-m receiver; and a group of signal-channel circuits used for separating, detecting, and recording the data contained in the output of the receiver.

The antenna system usually contains a highly directional antenna or combination of antennas controlled by servo units

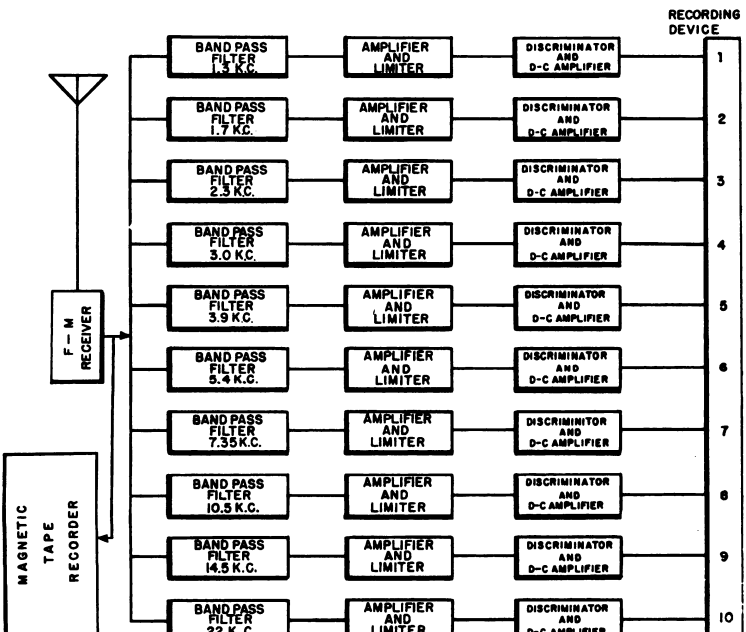

Figure 11-7.—Block diagram of a 10-channel receiving station.

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to provide automatic tracking of the missile, thus insuring maximum signal reception. The receiver is generally of the standard f-m type described in chapter 12 of *Basic Electronics*, NavPers 10087, but which is designed to tune in the telemetering bands.

The output of the receiver is a complex, frequency-modulated signal containing all the data impressed on the transmitter carrier wave. In the system shown (fig. 11–7), this includes frequency components representing all the 10 subcarriers, each of which is frequency modulated by the missile-data voltages.

The complex output of the receiver is applied to the inputs of all 10 signal channels. Each channel contains a filter which allows only a narrow band of frequencies to pass. The center frequency of the band accepted by the filter in each channel corresponds in value to one of the subcarrier center frequencies.

After passing through the bandpass circuits, each subcarrier is amplified and then applied to a limiter circuit, which removes any amplitude variations present. The resulting signal, a frequency-modulated wave of constant amplitude, is next applied to a discriminator. In this stage, the frequency variations present in the signal are converted into amplitude variations. Thus, each discriminator output is a d-c voltage, the instantaneous voltage of which is a measure of the missile function monitored in the corresponding transmitter channel. The d-c data voltages are applied to direct-coupled amplifiers to which recording galvanometers or other types of recording devices are connected.

Basic Recording Devices

The data developed by the receiving equipment must be reduced to permanent form in order that it can be studied effectively. This is accomplished by the use of various types of recording instruments. Some of the basic types employed include (1) magnetic-tape recorders, (2) galvanometer oscillographs, and (3) numerous kinds of photosensitive equipment including light-sensitive oscillographs and cameras.

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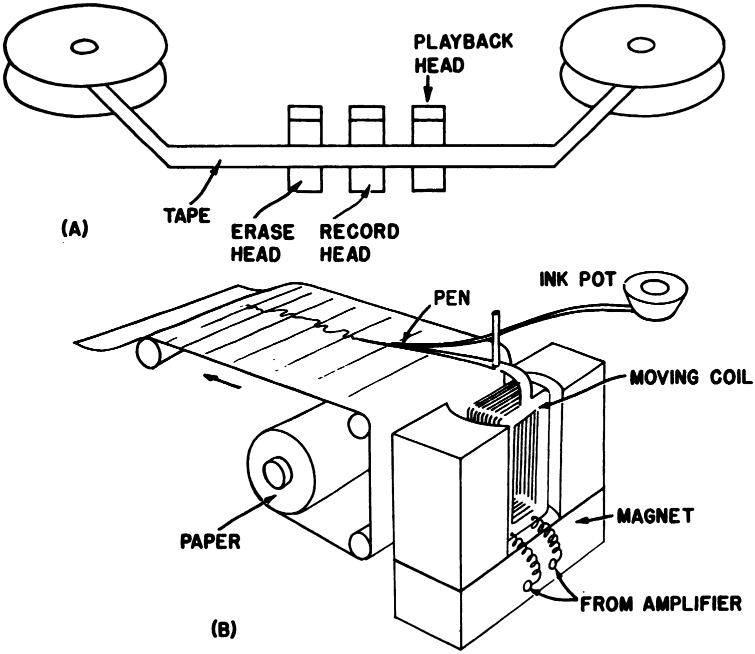

Figure 11–8.—(A) Magnetic-tape recorder; (B) galvanometer oscillograph.

The essential elements of a magnetic recorder are shown in simplified form in (A) of figure 11–8. These recorders are often used in the manner shown in figure 11–7 to collect in very compact form all the data contained in the output of the telemetering receiver. The recording provides a means by which individual channels of data can be recovered at a later time by playing back the tape through the appropriate decoding circuits. The information desired can then be recorded by the use of one of the other types of recorders such as the galvanometer oscillograph.

The basic mechanism of the direct writing oscillograph employing a D'Arsonval galvanometer is shown in (B) of figure 11–8. The instrument contains a self-inking pen which is moved across the recording paper by the D'Arsonval assembly. (See chapter 9 of *Basic Electricity* for information concerning this instrument.) The data voltages are applied

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to the coil of the galvanometer which is mounted in the field of a permanent magnet. The resulting motion deflects the pen laterally by amounts proportional to the voltage applied. The recording paper is moved under the pen at a constant speed by a motor drive so that the pen traces a graph of the varying data values.

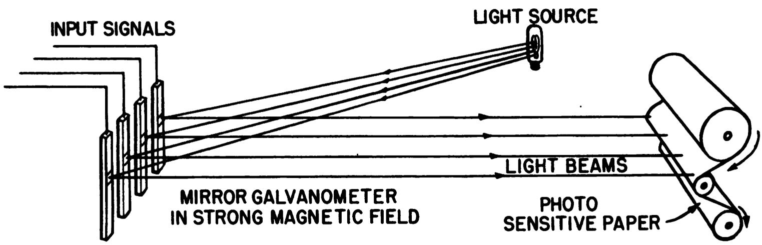

Figure 11–9.—Photosensitive galvanometer recorder.

A galvanometer oscillograph employing light-sensitive paper and capable of recording several channels simultaneously is shown in simplified form in figure 11–9. This recorder contains a number of galvanometer units. To each of the movable elements a small mirror is attached. Images of a light source are reflected from the mirrors onto a roll of photosensitive paper. The output voltages of the d-c amplifiers in the decoding channels of the receiving equipment are connected to the galvanometers, thereby causing the movable elements and mirrors to rotate. This action deflects the light images falling on the moving paper and produces traces which represent the variations of the data voltages. The paper is moved at a constant speed by means of a motor.

In some receiving systems, the outputs of the d-c amplifiers are connected to the input circuits of cathode-ray oscilloscopes. And when the sweep voltage of the scope is properly synchronized with the data signals, the traces on the oscilloscope tube represent the variations of the data signal. Cameras are attached to the oscilloscopes to record the traces on film.

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PULSE TELEMETERING SYSTEMS

Pulse telemetering systems operate on a time-sharing basis; that is, they transmit separate items of information one at a time and in a regular sequence. The missile data supplied by all the channels are transmitted on the same carrier wave; but each channel is sampled for comparatively short intervals of time and is permitted to modulate the

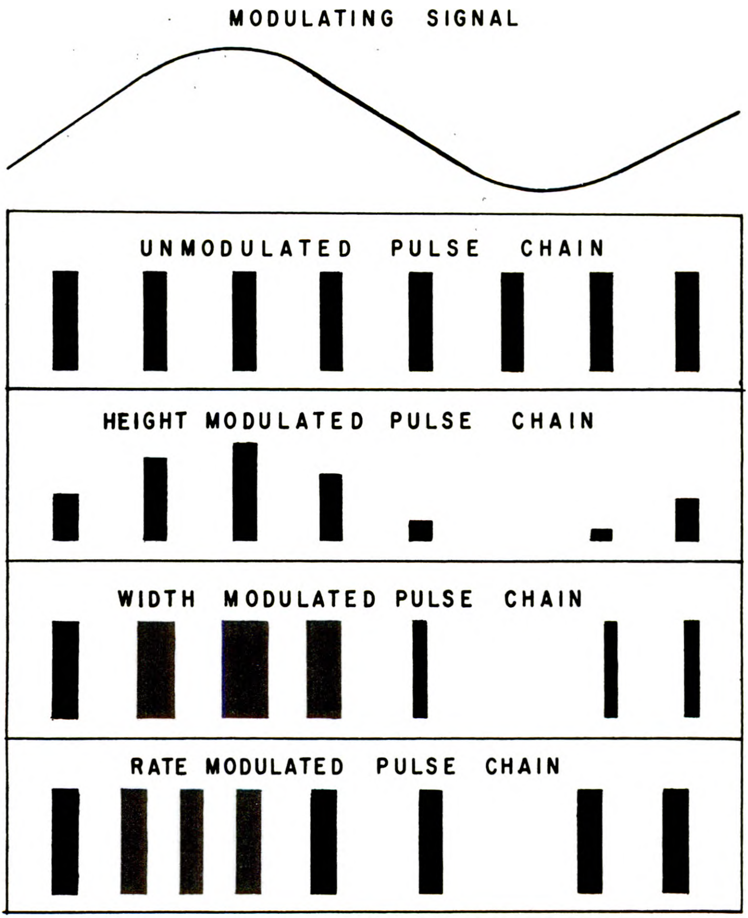

Figure 11–10.—Basic types of pulse modulation.

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transmitter only during those intervals. The information to be telemetered is contained in a series of voltage pulses, some characteristic of which is made to vary in turn with each of the missile functions monitored.

There are several basic methods by which voltage pulses can be made to represent accurately the varying quantities measured in the missile. In all these methods, a particular property of a train of pulses is caused to change in accordance with the quantity to be represented. As indicated in figure 11–10, the property may be pulse height, pulse width, or pulse rate. In pulse telemetering, the data voltages provided by the input transducers are selected in a specific order by a commutator, or switching device. Each data voltage is applied to the pulse generating circuits so that it causes a proportional variation in the amplitude, width, or rate of the pulses.

After modification by the data voltages, the pulse series is applied to a modulator which impresses the individual pulses upon the r-f carrier wave radiated by the transmitting antenna. The carrier may be modulated either in frequency or in amplitude.

The P–W–M/F–M System

The pulse-width-modulated/frequency-modulated, or P–W–M/F–M system is one frequently employed in missile telemetry. The pulse series containing the missile information can be represented as in figure 11–11. If N channels are to be monitored, pulses are generated in sets, or sequences, of N square-wave variations; and each set is separated from the set following it by the SYNCHRONIZING INTERVAL, a comparatively long period of time during which no pulses occur.

The input transducers in the missile are designed to produce data voltages ranging in value from 0 to 5 volts. Each datum is used to vary the width of one of the pulses in the series. The series of modified pulses is applied to the modulator which shifts the frequency of the carrier wave by amounts proportional to the widths of each successive pulse. After all the channels have modulated the carrier in this way, the synchronizing interval occurs, separating the last pulse

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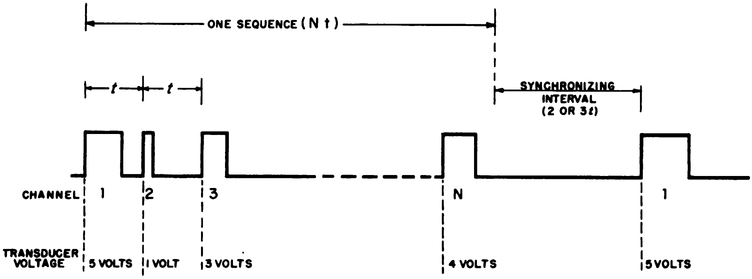

Figure 11–11.—Pulse series for pulse-width telemetering.

of one sequence from the first of the next, and the samplirg process is then repeated.

AIRBORNE PULSE EQUIPMENT.—Pulse-modulated missile information in the form illustrated in figure 11–11 can be transmitted by equipment which is comparatively small in size, light in weight, and simple in design. The major components carried in the missile for gathering, encoding, and transmitting the data are shown in the block diagram in figure 11–12.

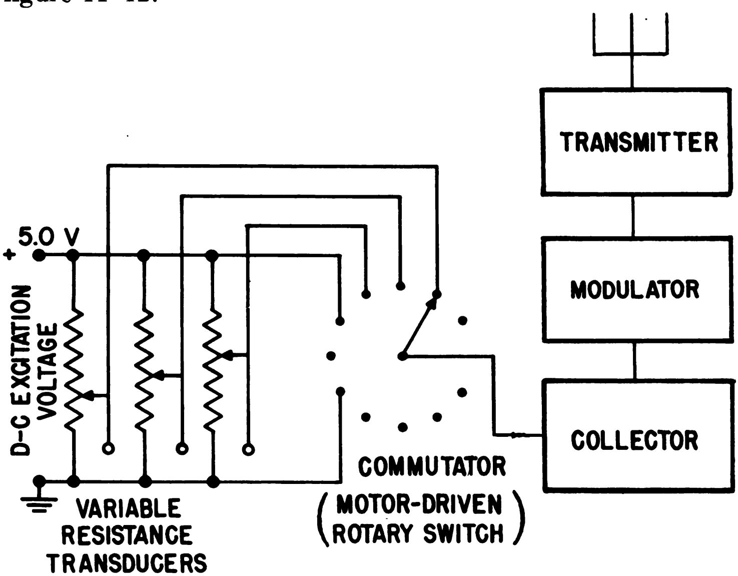

Figure 11–12.—Missile-borne pulse equipment.

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In this system, the missile functions are monitored by transducers of the potentiometer type, one of which is provided for each function. A COMMUTATOR connects the data voltages in sequence to the COLLECTOR, which contains the pulse generating circuits. The commutator is a mechanical switch in the system illustrated. During each cycle of operation, it applies the full excitation signal, or 5 volts, as well as zero volts to the channel collector. The pulses resulting from these inputs are used in calibrating the equipment.

The pulses produced by the collector (fig. 11–12) are modulated in width. The greater the amplitude of the transducer voltage, the wider is the corresponding pulse applied to the modulator. The transmitter is frequency modulated by the modulator in the manner employed in the f-m equipment of the F–M/F–M system.

RECEIVING EQUIPMENT—Pulse telemetering receiving equipment contains several major components which are essentially the same as the corresponding units used in the F–M/F–M system. These include the antenna system and the receiver. The principal differences in the two receiving systems are in the circuits which decode the incoming signals. Pulse decoding circuits also differ among themselves in that each must be designed for the specific type of pulse modulation employed. The basic units of a typical P–W–M/F–M receiving station are shown in block-diagram form in figure 11–13.

The pulse-width-modulated, frequency-modulated signal

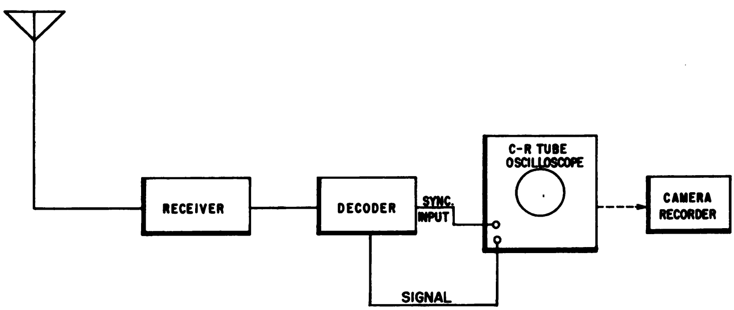

Figure 11–13.—Basic pulse receiving equipment.

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is received by the antenna and applied to the receiver, the output of which is taken from a discriminator. The output signals consist of the width-varying pulses containing the missile information. This is fed to two separate circuits in the decoder, one of which develops a voltage used for the horizontal sweep signal of a cathode-ray oscilloscope. The other circuit in the decoder amplifies the pulses and applies them to the vertical deflection circuits in the oscilloscope. The pulse train thus provides the signals used for synchronizing and sweeping the beam in the cathode-ray tube, and the pulse information is displayed as a series of video waveforms occurring in the order in which they were developed in the transmitter unit. The face of the cathode-ray tube is photographed by a movie camera mounted on the scope. The camera thus functions as the recording device in this type of receiving station.

Commutating Devices

Commutating devices are used in pulse telemetering equipment as switches which automatically sample the channel information in the required rate and sequence. Two kinds of commutators are used: mechanical and electronic. The former are motor-driven, rotary switches; the latter usually consist mainly of a group of multivibrator circuits.

The physical characteristics of a typical mechanical commutator are shown in figure 11–14. The unit is a four-section switch containing 30 contacts per section and equipped with a shorting type contact wiper. The rotor contacts are mounted on the spring-loaded wiper assembly. A pair of contacts are attached to each of two fiber gears driven by a steel worm gear attached to the shaft of a miniature, permanent-magnet motor. The rotor speed is governed by the motor-supply voltage, which can be varied to adjust the rate of sampling.

Motor-driven commutators can be designed to provide typical sampling rates of 900 samples per second. With the average number of information channels used, this allows each channel to be sampled approximately 20 times per second.

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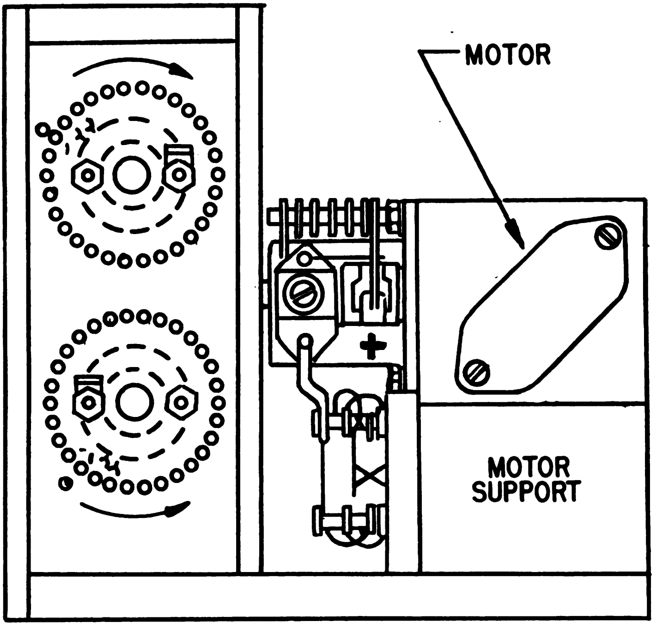

Figure 11–14.—Motor-driven commutating device.

ELECTRONIC COMMUTATION.—The multivibrator, the basic circuit used in electronic commutation, is discussed in chapter 7 of *Basic Electronics*. The use of the multivibrator as an electronic switch is also described in the same text in chapter 13, page 619. The trainee is referred to these chapters for information on the theory and operation of the circuits. Their application as commutating devices in pulse telemetering can be indicated by the example shown in figure 11–15, a block diagram of an airborne unit.

The MASTER KEYER is a free-running multivibrator used to generate the initial pulse of each sequence. This voltage is applied to the CHANNEL COLLECTOR and also as a triggering pulse to the multivibrator in channel 1. When triggered, the latter delivers one output pulse to the collector and a signal to the multivibrator in channel 2 which, in turn, applies a pulse to the collector and triggers the multivibrator of the

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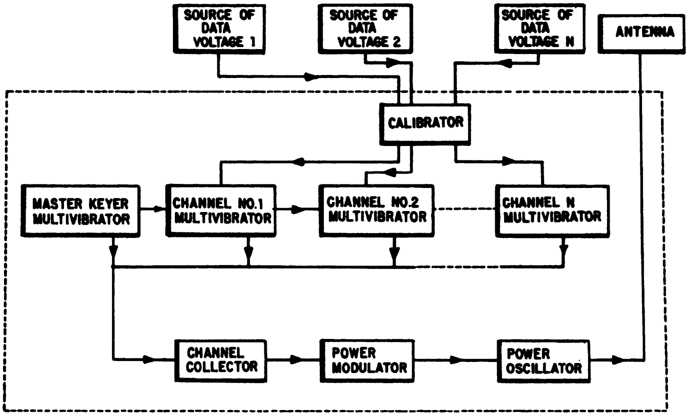

Figure 11-15.—Block diagram of airborne telemetering unit with electronic commutation.

next channel of the sequence. This process is repeated until all the channel multivibrators have operated.

Unlike the master keyer, the channel multivibrators are of the monostable type. The circuit produces no output until triggered by an input pulse; and when this occurs, it produces one pulse and then returns to an inactive state until triggered again. The width of the pulse produced depends upon the circuit constants and also upon the value of the applied voltage. In the case of the channel multivibrators, the width of the output pulse each applies to the collector is a function of the data voltage applied by the associated transducer.

After all the channel circuits have operated once to complete one sequence, the switching system remains quiescent until the master keyer again initiates another cycle of commutation. The pulses in the output of the collector are applied to the modulator, which modulates the carrier generated by the power oscillator.

CHECKING, CALIBRATING, AND ADJUSTING TELEMETERING UNITS

The proper operation of telemetering equipment is a matter of the highest importance in missile evaluation. The equipments employed are usually fairly complex and require great

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care in calibration, adjustment, and repair. All these operations demand specific knowledge of the equipment involved as well as considerable skill and experience on the part of the technician carrying them out. No overall methods are valid for all systems since each is composed of specialized units designed for the particular purpose for which they are used. The GF concerned with adjustment and maintenance of telemetering equipment must rely wholly upon information given in the publications pertaining to the particular units; and the detailed procedures for calibration, adjustment, and repair usually included in these must be followed exactly.

While no checks and tests can be described in detail, there are a few which are of sufficient general importance to be required in most instances. These include measurements of transducer outputs, checking and adjustment of oscillator frequencies, and checks of the output of pulse generating circuits.

Transducer outputs are checked against standard values given in the equipment handbook which indicate normal operation of the instrument in response to simulated missile conditions. The measurements of voltage must be done only with the type of instrument authorized in the handbook; and any adjustment must be made according to the directions given.

As indicated in table 11–1, subcarrier oscillators in F–M/F–M systems must operate at certain assigned center frequencies and must be deviated in frequency only within certain well-defined upper and lower limits. The center frequencies generated by each channel oscillator must be measured and adjusted to the assigned value; and the deviation of the subcarrier signals must be checked by applying standard input signals to the modulating circuits. The master oscillator of the telemetering transmitter must also be checked for proper frequency and tuned to the assigned value in the telemetering band.

Pulse generating circuits are checked for proper operation by the use of test signals developed in standard signal sources and by use of authorized testing and measuring equipment.

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QUIZ

1. What factor makes telemetering a necessity in the guided missile field?
   a. A missile cannot be tested by a human pilot.
   b. Missiles generally fly at higher altitudes than aircraft.
   c. Telemetering supplements the guidance command signals.
   d. It would be dangerous to fly an aircraft in close proximity to a missile.

2. Initial testing of a new missile system is made by
   a. telemetering
   b. a flight simulator
   c. wind tunnels
   d. stress analysis

3. In order that the operation of the overall system might be made known under actual firing conditions, __________ was designed and produced for missile use.
   a. a specialized flight simulator
   b. a check-out console
   c. special telemetering equipment
   d. an accurate hydraulic test stand

4. An early type of radio telemetering was used to
   a. measure the depth of the ocean
   b. transmit weather data
   c. read the speed of the engine aboard ship
   d. measure fuel consumption of military engines

5. Telemetering permits the measurement and study of __________ from a remote point.
   a. aerodynamic characteristics
   b. structural stresses
   c. missile performance
   d. component layout

6. The primary requirement of a missile telemetering system is the ability to __________ of data in a short period of time.
   a. gather, decode, and process a large amount
   b. gather, transmit, and process a small amount
   c. gather, decode, and process a small amount
   d. gather, transmit, and process a large amount

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7. The F–M/F–M telemetering system employs a/an __________ carrier.
   a. amplitude-modulated
   b. frequency-modulated
   c. pulse-modulated
   d. phase-modulated
8. The oscillator which produces the signal corresponding to a bit of information is called a/an
   a. subcarrier oscillator
   b. master oscillator
   c. local oscillator
   d. secondary oscillator
9. In F–M/F–M systems, the number of missile functions telemetered may be as high as
   a. 14
   b. 18
   c. 30
   d. any number
10. The device which frequency modulates each subcarrier oscillator is called a/an
    a. pickup
    b. end instrument
    c. telemeter pickup
    d. transducer
11. The carrier frequencies allocated for use in telemetering are in the band from
    a. 216 mc. to 235 mc.
    b. 216 kc. to 235 kc.
    c. 200 kc. to 300 kc.
    d. 200 mc. to 300 kc.
12. The transmitted carrier is picked up at the receiving station and the subcarrier signals are separated by means of
    a. low pass filters
    b. bandpass filters
    c. high pass filters
    d. discriminators
13. The permissible frequency deviation in the standard subcarriers is
    a. $\pm 7.5\%$
    b. $\pm 15\%$
    c. $\pm 20\%$
    d. $\pm 25\%$
14. The subcarrier frequency used for a specific function will be determined by
    a. the available oscillators
    b. no specific factor
    c. the frequency of the function
    d. the amplitude of the function

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15. The transducers convert the information to be measured into
    a. a-f signals
    b. r-f signals
    c. d-c voltages
    d. constant-frequency signals
16. An example of the variable-reluctance transducer is the
    a. accelerometer
    b. linear potentiometer
    c. inductance pickoff
    d. capacitance pickoff
17. The saturable reactor is not used to measure voltages developed in high impedance sources because
    a. it will be unable to measure these voltages
    b. it is a power consuming device
    c. it is too large a unit to be used in proximity with other units
    d. there are no applications of this device
18. A variable-resistance transducer usually would be used to measure
    a. physical displacement
    b. d-c level
    c. frequency variations
    d. phase variations
19. Which two oscillators are most commonly used as subcarrier oscillators?
    a. Hartley and Armstrong
    b. Phase shift and Colpitts
    c. Colpitts and Armstrong
    d. Hartley and phase shift
20. Missile telemetering transmitters differ principally from standard transmitters in
    a. physical form
    b. frequency
    c. operation
    d. basic circuitry
21. The antenna system of a telemetering receiving station contains ____________ antennas.
    a. highly directional
    b. multidirectional
    c. nondirectional
    d. low gain
22. The center frequency of the band accepted by the signal channels in the receiving station corresponds in value to the
    a. maximum frequency deviation developed by the missile data voltages
    b. maximum frequency of operation of the transducers
    c. center frequency of the subcarrier oscillator
    d. band of frequencies allocated for telemetering purposes

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23. The outputs of the signal channels are applied to
   a. recording devices
   b. dissipation networks
   c. servo systems
   d. antenna positioning devices

24. The general purpose of a magnetic recorder is for
   a. data recovery at a later time
   b. direct readings
   c. fidelity of reproduction
   d. ease of use

25. A pulse telemetering system operates on a ____________ basis.
   a. frequency sharing
   b. phase sharing
   c. time sharing
   d. amplitude sharing

26. In many cases, the transducer used in the P–W–M/F–M system is of the ________ type.
   a. variable-resistance
   b. variable-reluctance
   c. variable-capacitance
   d. any of the above

27. Commutating devices are used in pulse telemetering equipment as
   a. reducing devices
   b. switches
   c. power supplies
   d. multivibrators

28. Motor driven commutators are designed to provide typical sampling rates of not more than
   a. 400 samples per second
   b. 800 samples per second
   c. 900 samples per second
   d. 1,000 samples per second

29. Electronic commutation is provided by (a)
   a. drive motor
   b. multivibrator
   c. reed vibrator
   d. all of the above

30. For proper operation of missile telemetering equipment, which of the following is the requirement of principal importance?
   a. Checking, adjusting, and calibration
   b. Cleanliness of equipment
   c. Low power requirements
   d. Complex operation

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CHAPTER 12

MISSILE HANDLING AND TESTING

The material in the preceding chapters pertaining to basic missile systems, components, and units serves as background information for the GF in the performance of his primary technical duties. Among the more important classes of duty are missile handling and testing, which are discussed in this chapter. Closely related to these are the duties involving maintenance and repair, the basic procedures of which are considered in the chapter following.

Missile handling is the subject matter of the first section of this chapter. The term HANDLING, when applied to a missile system, refers to the procedures and steps taken with missile components from original issue through assembly and expenditure of the weapon. The principal steps are receipt of the various sections; inspection; stowage; testing of system operation; assembly of the sections to form an operational missile; and the loading of the weapon on the launching aircraft. Handling also includes procedures used with missiles not fired, which must be unloaded from the aircraft and disassembled.

An important phase of missile handling is testing of the system operation. Prior to use, every missile must pass one or more complete tests designed to check the guidance and control systems under conditions resembling those of actual flight. To facilitate this kind of testing, special test sets have been developed for each missile system. One of the major requirements of the GF is proficiency in the use of this type of equipment, which is described briefly in the second section of the chapter.

In addition to specialized test equipment, the missileman must understand and use many general-purpose test instru-

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ments as well as various gages and measuring tools. Some of the more important examples of this class are discussed in the concluding section. Other instruments, not discussed in detail, are covered by references to appropriate chapters in the companion texts of this course, *Basic Electronics*, NavPers 10087, and *Basic Electricity*, NavPers 10086.

MISSILE HANDLING

Missile Logistics

It is desirable to introduce the subject of missile handling by considering first the processes by which missile sections and components move from the manufacturer to various missile naval activities and finally arrive at the squadrons which expend the missiles in assembled form. These processes are indicated by means of a flow diagram in figure 12–1. The principal missile organizations involved in the supply, or logistic, pattern are located in naval air stations, at naval ammunition depots, on aircraft carriers, and those attached to FASRons.

NAS PROCEDURES.—Certain naval air stations are designated to provide missile logistic support within surrounding areas. Each of these stations is supplied with missile equipment from two major sources: items such as guidance and control sections and spare components are received directly from the manufacturer; and ordnance units are supplied from naval ammunition depots.

The missile responsibilities of the NAS are met by the coordinated actions of the Guided Missile Service Unit (GMSU), the NAS Supply Department, and the NAS Ordnance Division. The Supply Department is responsible for the receipt, inspection, stowage, and issue of all missile items except ordnance, which is handled by the Ordnance Division. Each of these organizations prepares reports and keeps records pertaining to the types of items handled.

The Supply Department maintains an auxiliary storeroom in the GMSU shop area and stocks it with the spare parts required for maintenance of missile sections and test equipment. Parts are drawn when needed by the GMSU tech-

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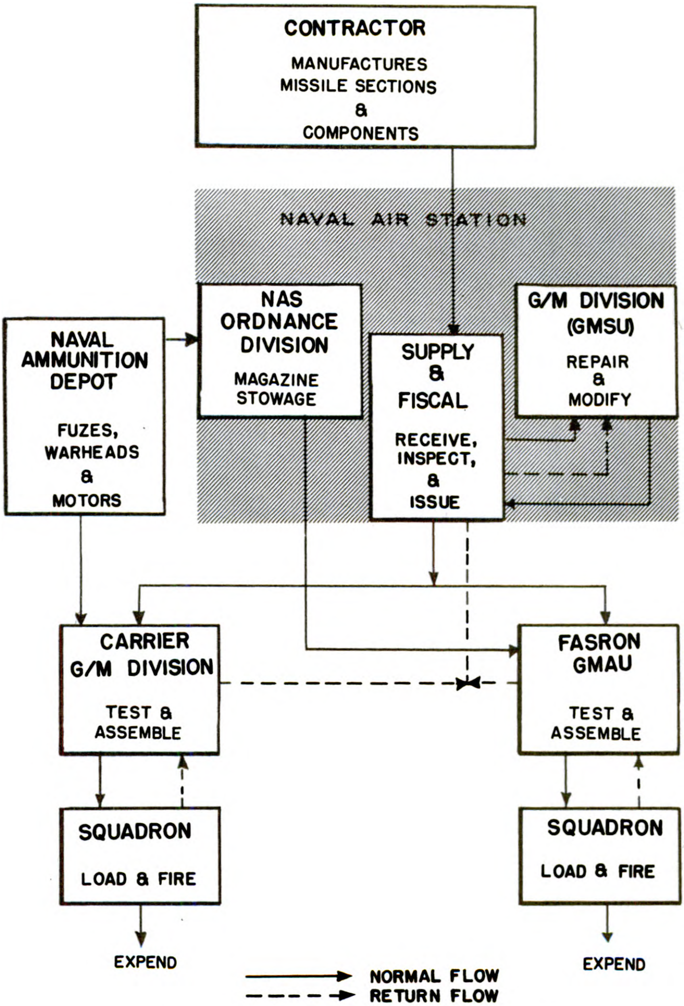

Figure 12-1.—Missile supply flow diagram.

nicians, who sign for them on a master issue sheet and also fill out stub requisitions listing the supplies drawn.

The clerical and technical work of the GMSU is done by personnel of the Log Room and the Material Section. In the Log Room, the maintenance workload is planned; job

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orders are prepared; and entries are made in missile logbooks showing all checks, repairs, or modifications made on the corresponding missile units.

The Material Section draws "raw" items (those requiring tests, modification, or repair) from Supply, and turns in to the Log Room the logbooks accompanying each of the units. When the work is completed, the Log Room designates certain units as Ready for Issue (RFI). These are returned to the Supply Department where they are packaged and placed in RFI storage, from which requisitions by squadrons, FASRons, and CVA's are filled.

As indicated in figure 12-1, a FASRon supporting a squadron having missile capabilities receives all necessary missile items from the NAS Supply and Ordnance Departments. Attached to the FASRon is a Guided Missile Augmenting Unit (GMAU), which makes operational tests on the sections received and assembles them in final form. The GMAU does no major repair or overhaul of the missile equipment; its repair function consists principally of the replacement of faulty components with new plug-in assemblies. All major units which cannot be repaired by such replacement are returned through normal supply channels to the naval air station.

An aircraft carrier with missile capabilities receives sections and components in much the same way as the FASRon except that ordnance items are supplied it from a naval ammunition depot. Operational tests and the assembly of missile sections are accomplished by a Guided Missile Division, the functions of which are substantially the same as those of a GMAU.

GF personnel serving at the various missile activities employ authorized handling procedures and use many kinds of equipment in the performance of their duties. The general features of these procedures and the related equipment are described in the following pages. The subjects considered first are the manner in which the missile sections are packaged upon arrival at the activity using them and the methods employed with the various sections which must be unpacked prior to operational testing and stowage.

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Receiving, Unpacking, and Inspection

No missile is received by a missile activity completely assembled and ready for firing. The major components are packed separately; and the total equipment required to assemble one missile may be enclosed in as many as six or seven containers.

Ordnance items, which include warheads, fuzes, fuze boosters, rocket motors, motor igniters, and tracking flares, require separate packaging. Several pieces of the same type of ordnance unit may be enclosed together for shipment, but different units are packaged separately.

Wings and fins are usually shipped in sufficient quantity to outfit several missiles. In some cases, both are packed in the same container; in others, they arrive packaged separately. The control section of the missile, which includes the guidance equipment, is shipped in a single can, which also encloses the electrical cables and hardware required for the complete missile assembly. If the missile has provisions for the use of replaceable plug-in components, these are shipped separately.

Upon receipt of missile items by a using activity, an inventory of the shipment is made by checking the received items against the shipping invoice. At the same time a visual inspection of the containers is made for physical damage present which might indicate damage to the contents. Any discrepancies noted are recorded on the receiving inspection sheet.

After the receiving inspection is completed, the containers are separated according to contents in preparation for stowage or unpacking. Certain items are stowed in the containers, while others must be unpacked upon receipt.

Reusable shipping containers.—The components and sections are received in reusable metal containers, which are specially designed for the particular items they enclose. The construction of the containers permits the items to be packed so that damage resulting from rough handling during shipment is reduced to a minimum. The design of the container is an important factor in the handling of missile equip-

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ment. For example, the package provided for the control section of a particular missile is constructed so that operational tests can be performed without removal of the units from the enclosure. Upon receipt, these units are placed in stowage without unpacking; and all required tests can be made by means of a special "in-package" test set. The equipment is unpacked only when needed at the time of final assembly.

In most systems, however, equipment such as control and guidance units must be unpacked for testing and subsequent stowage. A shipping can used for packaging a control section of this type is shown in figures 12–2 and 12–3.

Figure 12–2 shows the complete container including the packing material and the parts used to secure the unit in place. The packing material, or blanket assembly, is shown at the right. It is made principally of rubberized-hair, and when packed, it encloses the missile units so as to protect them from physical shock. The two end closures of the can are shown removed.

Figure 12–3 gives a closer view of one of the end closures which contains a compartment for the missile log and other papers which accompany each missile. It also includes a humidity indicator which indicates the condition of the

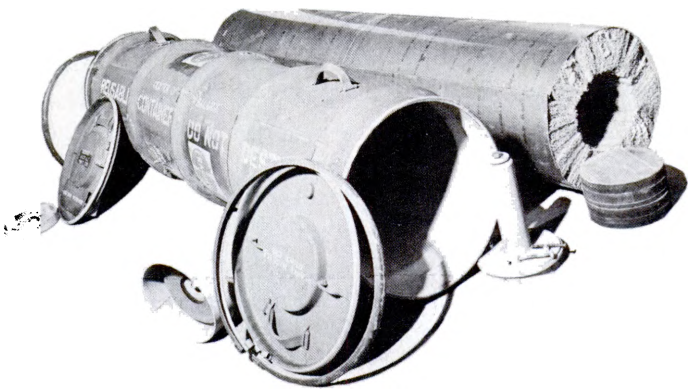

Figure 12–2.—Missile shipping container with packing material.

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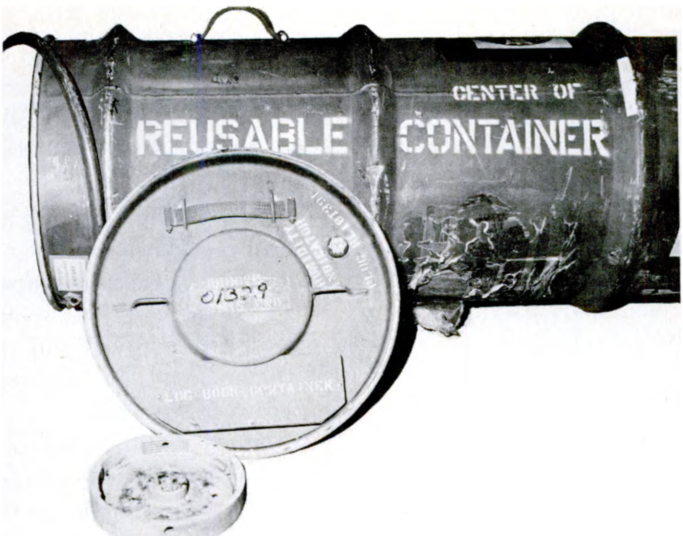

Figure 12–3.—End closure of container showing logbook stowage and humidity indicator.

desiccant, or dehydrating agent, that is placed in the container to limit the moisture content of the enclosed air.

UNPACKING AND INSPECTING.—Typical procedures for unpacking and inspecting missile sections upon arrival can be illustrated by a brief summary of those pertaining to the shipping container shown in figures 12–2 and 12–3. A chain hoist is useful but not essential as a handling tool, and special tools needed are enclosed in a cloth bag shipped inside the can.

1. The container is first placed on the floor in a horizontal position. The seals on the closure rings are broken, and the rings are removed to permit removal of the closures.

2. The cloth bag, which contains two nylon straps and an eyebolt, is removed; and the eyebolt is installed in one of the end caps of the missile section.

3. If a hoist is available, the can is raised to a vertical position and the hoist hook is attached to the eyebolt. The container is held firmly while the hoist is worked to pull the

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section (surrounded by the blanket assembly) free from the can.

4. If no hoist is available, the container is left in a horizontal position and the equipment and blanket assembly pulled from it. (It is advantageous to loop the nylon straps around the assembly to assist in sliding it free.)

5. The blanket assembly is removed by wrapping the nylon straps about it, one placed about two feet from either end, and applying force to unlatch the seal. Wrapping paper, the desiccant assembly, and all sealing tape are removed from the missile unit. Locking screws are removed and the cables packed in the section are taken out. The forward end cap and aft adapter are removed from the unit.

6. The missile units are inspected carefully to be sure that all necessary components are present and that none have been damaged in shipment. Further checks are made for the presence of foreign materials, abrasions, loose parts, damaged insulation or defective lacing on the wiring harness, and for bent connector pins.

7. The shipping container is then readied for reuse or else disposed of in accordance with local regulations. The humidity indicator is removed from the end closure and wrapped in waxed cloth to prevent discoloration by moisture in the outside air. The hole left by its removal is closed with the cover provided; all adapters and packing parts are replaced in the container; and the end closures are secured. Upon reuse, it is packed for shipment in the same manner in which it was received.

It is necessary also to describe the procedures used with missile sections, of the type mentioned above, which are tested in the shipping containers both upon receipt and at regular intervals while the sections are in stowage. These sections are parts of missiles which employ guidance equipment other than radar and, hence, contain relatively few parts and circuits. The test equipment used for checking the operation of radar guidance sections and control systems is considerably more elaborate and requires a lengthier discussion, which is given in another part of the chapter.

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In-Package Testing

Both the equipment and the procedures of in-package testing are designed for efficient handling and testing requiring minimum time and effort. The missile systems for which this kind of testing is exceptionally well suited are those employing passive homing guidance and containing wing-control units of the all-pneumatic type (described in chapter 9). In most cases, it is required that the guidance and control units receive operational tests upon arrival and at four-month intervals thereafter.

In-package testing is done with two major units: an IN-PACKAGE TEST EQUIPMENT, and GO, NO-GO TEST SET. The former is a small assembly mounted inside the missile shipping container; the latter is a larger, portable unit, which can be moved to the packaged containers to be tested. (When placing the missile sections in stowage, it is required that access aisles be left in the compartment to permit the test set to be brought up to any of the sections.)

The operation of the test set, which is entirely automatic, includes a self-check function as well as provision for operational checking. The uses of the set in both modes of operation can be understood by means of a brief description of the test procedures.

1. To test a packaged section, access must be obtained to the In-Package Test Equipment by removing one of the end closures of the shipping container. Just inside is a quick-connect plug to which a cable from the test set is attached. The test set is then connected to a high-pressure air (or nitrogen) outlet; the outlet valve is opened; and a quick check is made for the presence of leaks. Electrical power is obtained by plugging the power cord of the set into a 115-volt, a-c outlet and pressing the button labeled MAIN POWER. (At this time, holding magnets mounted in the lower part of the set are energized, holding it firmly against the steel deck.)

2. The test set is then given a self check by throwing a selector switch to the position so marked and by observing the results of two cycles of operation, initiated by switching

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first to the Out-of-Tolerance position and next to the In-Tolerance position. In the first position, a satisfactory preliminary check is indicated by 18 panel lamps which become successively illuminated, followed by a red lamp marked NO becoming bright. This cycle requires two minutes.

The second cycle of the self check is begun by pressing the Reset button and throwing the selector switch to the In-Tolerance setting. After a 2-minute cycle, satisfactory operation is indicated by each of the 18 panel lamps becoming dark and a green lamp labeled GO coming on.

3. If the indications described above are not given, the test set must not be used to test missile units. No repair of the equipment should be attempted. If any indication of improper operation is present, the equipment must be returned to the source of supply and another set used for checking the missile units.

4. After a satisfactory self check, the operational testing of a missile section proceeds by removal of the padding in the shipping container to expose a second quick-connect plug to which the test set cable is mated. The Start button is pressed, and the test set is allowed to run through a two-minute cycle. The result is either GO (favorable) or NO (unfavorable). In the former case, the green lamp comes on and the 18 indicator lamps remain dark. The cable is removed and the desiccant, or dehydrating agent, inside the container is replaced with a regenerated package. The results of the test are recorded on a card mounted in the missile can, the padding is replaced, and the container is closed.

5. If the result is NO, this is evidenced by the red NO lamp glowing and by one or more of the 18 indicator lamps burning (thereby giving information as to which stage or stages contain malfunctions). In this case, the authorized procedures require another self check of the test set and additional operational testing of the missile unit.

If, on the second check, the result is again NO, the section is rejected. The result is recorded on the missile card in

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the container, and the outside of the shipping can is marked with the word NO.

If, however, the result of the second check is GO, the test cycle is repeated; if the result is again GO, this is considered sufficient to justify acceptance of the section. The fact that a normal condition was indicated only after repeated testing is recorded on the missile card, and the shipping can is marked acceptable.

The sections which pass operational tests satisfactorily are used either to make required replacements in missiles kept in ready service, or they are left in stowage awaiting assembly, the procedures of which are considered next.

Missile Assembly

Missile sections are assembled to form single operational weapons by missilemen of GMAU's and of Missile Divisions aboard aircraft carriers. Missile assembly, particularly that accomplished on shipboard, demands economy of time, personnel, and space; these requirements can be met only by experienced crew members, who can perform specific tasks in proper sequence while working effectively as a team and who can use the proper handling equipment.

Typical handling equipment includes sparkproof hand tools (required for work with ordnance units), tool belts (often required but not always mandatory), special lock wrenches, and larger devices such as assembly jigs and dollies or loading skids.

Examples of the larger class of assembly equipment are given in figure 12–4, which shows an assembly jig, and in

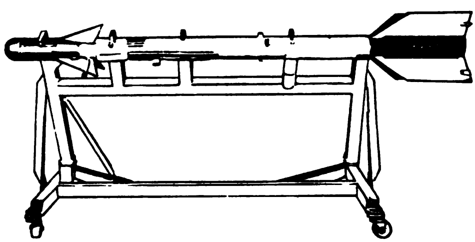

Figure 12–4.—Assembly jig.

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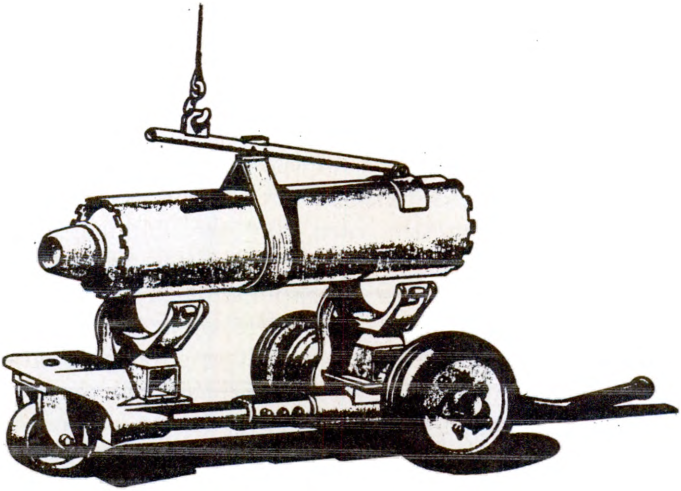

Figure 12–5.—Locding dolly.

figure 12–5, which shows a loading dolly. The jig serves to hold the heavy missile sections in place in proper alinement for assembly, and also provides index markings which are used to insure that the sections are set up in correct angular position before being locked together. The dolly (fig. 12–5) is used to transport the assembled missile from the assembly jig to the Ready Service Magazine or to the loading area.

The procedures for assembly can be represented in essential form by the following listing of major steps employed with a typical air-launched missile:

1. The missile sections are taken from stowage and moved to the assembly area by component-supply teams.

2. Two men of the assembly team place the ROCKET MOTOR on the assembly jig. Using air-driven screwdrivers, they begin assembling the fins which mount on channel rings on the shell.

3. At the same time, a third member of the team removes the INFLUENCE FUZE from its container and joins it to the rocket motor section by the use of a lock wrench of special design. This same crew member then removes and installs the INFLUENCE FUZE BOOSTER, attaching it within the fuze assembly.

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4. During these operations, the fourth and fifth members of the team have removed the CONTROL SECTION from the stowage container and placed it on the assembly jig. One of these men then unpacks the CONTACT FUZE and installs it on the control section. The other man attaches the WARHEAD, which also joins onto the shell containing the control units.

5. At this stage of assembly, the missile units are in two sections. These are mated and locked together by the use of air-driven screwdrivers. The missile is then lifted from the assembly jig and placed on the loading dolly for transport to the Ready Service Magazine or to the loading area.

THE READY SERVICE MAGAZINE.—An essential part of the missile supply "pipeline" aboard an aircraft carrier is the Ready Service Magazine, which serves as a source of supply for ready missiles which can be delivered within a few minutes after being ordered. In the Ready Service Magazine a number of missiles (often 20) are kept fully assembled, or nearly so except for a few minor adjustments and additions. Some missiles are stored in the RSM fully assembled; others require a few last minute preparations, such as charging the accumulators with air or nitrogen and installation of battery boxes. As the supply of ready service missiles is depleted, assembly of other missiles is under way for delivery to the loading and arming crews.

Loading, Arming, and De-arming

The procedures authorized for loading, arming, or de-arming guided missiles, as those employed with other types of ordnance, are based on considerations of safety and efficiency in handling and also on the characteristics of the specific weapon. Only the essential features of this phase of handling in air-launched missile operations can be considered in this discussion. These features, which are common to most missile systems, are indicated by examples given of standard preloading checks performed on the aircraft circuits and by listing the basic processes and safety precautions practiced by loading and arming crews on aircraft carriers.

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Preloading checks.—Prior to loading, several checks must be made of the aircraft circuits that initiate the action of the missile ordnance units. These checks are made on the jettison circuits, the firing circuits, and on the positions of several switches and circuit breakers in the cockpit.

The jettison circuits of the aircraft allow the pilot to release the missiles from the launcher during flight without firing the rocket motors. This is accomplished in most systems by firing one or two jettison cartridges located in the missile launchers. Before loading can begin, a check is made of the voltages present at each of the jettison-cartridge breeches with the circuit energized. The voltage actually present at each must be identical with the value indicated in the cockpit. Before installation of the cartridges, the circuits are deenergized and each breech is checked again to insure zero voltage to ground.

The firing circuits are given voltage checks (and in some cases, continuity checks in addition). The circuits are first energized and the voltage appearing at each launcher is measured to see that it is of the correct value. The circuits are then deenergized and checked for zero voltage to ground.

Before loading any missile on the launcher, the person in charge of the loading crew must insure that the cockpit switches controlling certain circuits are in the correct positions. In a system based on radar-type guidance, the switches and breakers are usually those of the following list, which also gives the necessary switch positions when loading, arming, or de-arming the missiles:

Master Arm Switch	Off.
Arming Control Switch	Off.
Radar Mode Selector Switch	Off.
Rocket Circuit Breaker	Out.
Jettison Switches	Off.
Landing Gear and Slats Indicator Circuit Breaker	In.

Loading.—Aboard a carrier, missiles are loaded onto the aircraft on the flight deck, as are other items of aviation ordnance, unless operational conditions require it to be otherwise. Also, missile-loaded aircraft taken aboard are spotted on the flight deck and unloaded. Loading or unloading can

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be done on the hangar deck only when authorized by the commanding officer.

The basic procedures of loading and the precautions to be observed by the loading crew and other personnel during the operation are briefly described in the following list:

1. The aircraft is spotted carefully to insure that sufficient deck space is provided under the launchers for the loading equipment and maneuvering by the loading crew.

2. Before loading is begun, all ordnance items must be checked to be sure that they are in the safe (unarmed) condition. A red pennant is attached to each rocket-motor igniter lanyard.

3. Loading crews wear special clothing: red helmets and jerseys, goggles, and hard-toed shoes. (Officers and CPO's wear yellow jerseys.) The goggles must be worn down over the eyes when installing or removing ordnance items.

4. When transporting the missiles to the aircraft on skids or dollies, care must be taken to avoid subjecting them to hot jet exhaust or to intense radiation from nearby electronic equipment.

5. At least three men are required to lift a missile from the skids to the aircraft launcher. Caution should be exercised to avoid injury from sharp surfaces or pointed projections. Fuze covers are left on until the last convenient moment before arming the missile.

6. If, during loading, a missile is dropped or severely jarred, it must be rejected and struck below for disassembly and inspection.

7. After the loading operation is completed, the missiles are checked for proper physical security on the launchers. All launcher test points are checked for correct resistance readings, which indicate proper mating of the missile to the umbilical connector, and a red "Live Ordnance" tag is placed in the cockpit. The tag (1) lists safe positions of switches and circuit breakers, and (2) serves to give warning to unauthorized personnel who may enter the cockpit.

ARMING.—Missiles loaded on carrier-based aircraft are armed only on the catapult, unless permission to arm elsewhere on the flight deck has been granted by the commanding

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officer. Safety in arming is achieved by cooperation of the pilot and the crew members in the use of distinct and well-understood hand signals.

A signal from the pilot indicates that he is ready for the missiles to be armed and that all switches and circuit breakers are in the correct positions. The signal is relayed by the arming crew chief to a man under each wing. Upon completion of the arming, the two crew members give signals to the crew chief who relays them to the pilot and to the catapult officer.

Any persons in the surrounding area must be warned not to stand forward or aft of missiles during or after arming, since an armed missile must be regarded with the same respect as a loaded gun.

DE-ARMING AND UNLOADING.—When a pilot returns aboard with missiles still on the launchers, the missiles must be de-armed and unloaded. It is necessary that the pilot advise the ship concerning the number of missiles being returned, whether live or dummy warheads are involved, and whether a firing attempt has been made. The de-arming and ordnance disposal crews are then alerted accordingly.

Missiles still on the launchers at the completion of an attack fall into one of two classes: those with which no attempt to fire has been made, and those which failed to leave the launchers after a normal firing attempt. Missiles of the second class are called "hangfires."

If a hangfire missile is smoking, the pilot jettisons it immediately. If no smoke is present, the pilot heads the aircraft in a suitable direction for a specified length of time. If no unsafe or unusual conditions are noted, the missile is then classified as a "misfire," and the pilot returns for a landing and for de-arming and unloading of the missile.

The procedures used with the two classes of returned missiles differ principally as to the personnel involved. De-arming crews handle missiles returned after no firing attempt has been made. After the pilot has come to a stop forward of the barriers and has signaled that all switches and circuit breakers are in safe positions, the missile crew begins de-arming.

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The rocket motor is made safe by pulling the igniter safety lanyard, and a red pennant is hung on the arming lanyard. If the missile contains batteries, these are removed from the outboard missiles. The pilot then taxies the aircraft to the parking spot where the crew completes the process of de-arming. If spotting charges are used, the arming rods are replaced. Battery boxes are removed from the inboard missiles, the jettison cartridges are removed, and the missiles are unloaded and struck below.

Procedures used with misfires require the services of an ordnance disposal crew that accompanies the de-arming crew and meets the aircraft as it taxies forward of the barriers. A visual inspection is made for signs of dangerous or unusual conditions. If any are noted, the plane is pointed in a clear direction, the engines are stopped, and the area cleared immediately of flight personnel. The ordnance disposal crew then assumes responsibility for handling the missiles.

If no dangerous conditions are found by the ordnance crew, the de-arming process proceeds and the missile or missiles are unloaded in the manner described above.

MISSILE TESTING

A guided missile is a complex weapon containing intricate circuitry and many kinds of mechanisms. The materials and workmanship employed in missile manufacture are the best obtainable; but regardless of the quality of the workmanship and parts, electronic units frequently develop malfunctions and mechanical systems often become inoperative. Because of the possibility of such failures, it is necessary to test missile units periodically to insure reliability.

Special test equipments, each designed for a particular missile system, are used to facilitate testing, which must be accomplished with accuracy and in minimum time. The principal types are SYSTEMS TEST EQUIPMENT, used for making operational tests of the control and guidance units; and COMPONENT TEST SETS, employed in checking replaceable plug-in components and other smaller items of the missile system.

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Systems Test Equipment

It is required that the guidance and control systems of each missile be given operational checks with authorized test equipment at intervals specified in the missile handbook and before being assembled in ready service missiles. In most Navy missile systems, the test equipment is in effect a flight simulator. The test set, by electronic and mechanical means, provides a series of input signals for the unit under test. The signals simulate conditions the missile might encounter in actual flight, such as displacement from the desired path, various angular accelerations, and different rates of motion.

The signals are applied automatically in an orderly sequence by a programmer so that they constitute a preset "flight program," each step of which subjects the missile unit to a different test. The response of the unit at each step is checked automatically by MONITOR circuits, which either accept or reject the missile response.

The "decision" of the automatic monitor to accept or reject the result of a particular test is generally based on an electrical comparison of the actual missile response with the desired response. This can be accomplished in numerous ways. Usually, a voltage is derived from the missile unit that is proportional in amplitude to the response tested. This is combined with a regulated standard voltage, the two signals being applied to a network which gives zero output only when the missile voltage is of the desired amplitude

The output of the comparison network is attached to the monitor circuits. And if the missile response is the correct value, or if it differs from it by an amount within certain tolerance limits, the automatic monitor permits the programmer to proceed to the next step of the preset test program. If, however, the missile response is incorrect, the monitor activates circuits which stop the sequence and give indications of malfunction to the operator; in most cases, by means of panel lamps and by meters.

One set of missile test equipment necessarily differs from another in circuitry and in testing procedure because each is

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a specialized system, designed for a particular missile. But most operate in accordance with the same general principles; and the end results achieved by all are similar—high-speed testing with accurate and reliable indications, either of malfunction or acceptable operation of the missile units.

A representative example of specialized test equipment is given in figure 12–6, which shows the major units of a typical shipboard checkout station. This equipment is designed to test missiles employing beam-rider guidance, the general operation of which is discussed in chapter 5 of this course.

Most of the missile components are mounted for testing on the TEST STAND shown at the right (fig. 12–6). An ANTENNA TEST STAND holds the missile tail assembly, which contains radar receiving equipment. Electrical energy is supplied to the missile units by cables attaching them to the POWER SUPPLY ASSEMBLY; hydraulic fluid under pressure is provided by the HYDRAULIC PUMPING UNIT. The results of the tests are indicated by meters and panel lamps on the TEST CONSOLE.

The checkout station can be used either for operational tests or to localize faulty operation to a specific missile component. During normal checkout procedures, test equipment operators are required principally for setting up the missile units and for observing the indications on the test console to determine whether the missile is checking correctly or incorrectly.

The test equipment has two modes of operation: the systems operational and the manual maintenance modes. The former is composed of two subsidiary modes: the power test and the systems check.

A complete check with the systems operational mode requires approximately 15 minutes. This includes the time for setup and connection, the test time, and the time required for breakdown after the test. The total time needed for a manual maintenance check varies from about 10 to 30 minutes, depending upon the number and complexity of the failures detected and upon the experience of the operator. The essential processes of the different modes are described in the following pages.

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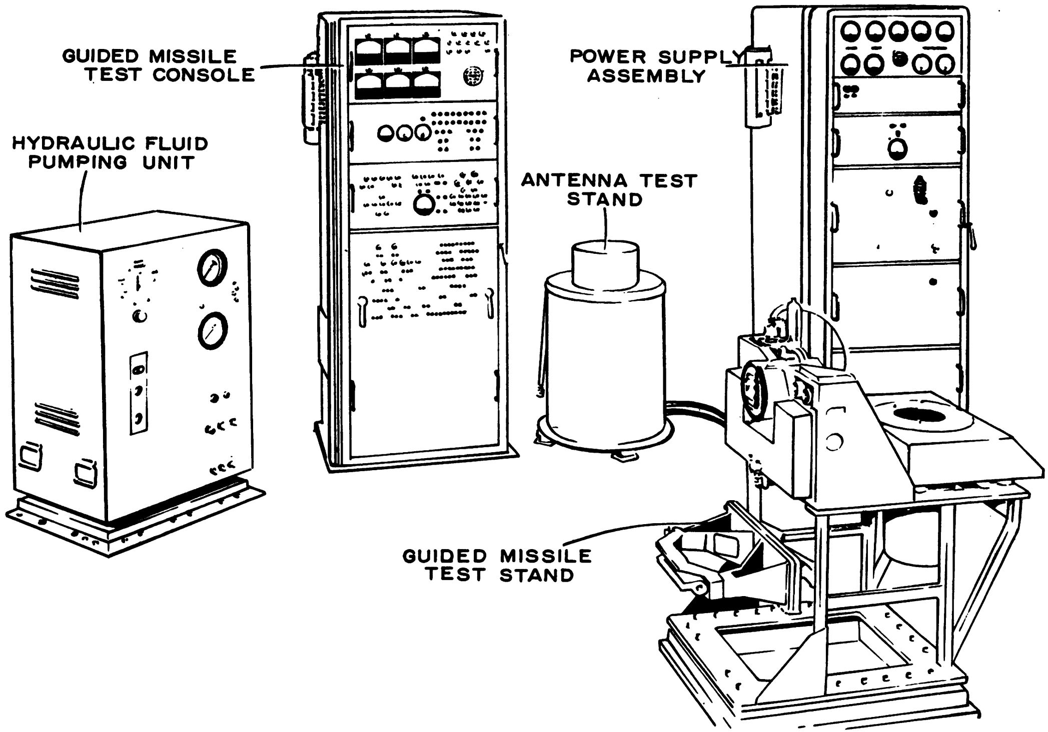

Figure 12-6.—Control system checkout station.

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THE POWER MODE.—In the power mode, the equipment shown in figure 12–6 checks the d-c and a-c supply voltages of the electronic and electrical components of the missile. A programmer selects the various voltages by means of a rotary stepping switch, and each voltage selected is checked and monitored on an accept-reject basis. Voltages within the required tolerance limits are accepted by the monitor, which permits the programmer to proceed with the test sequence.

Out-of-tolerance voltages cause the monitoring circuits to stop the testing process and to give a visual indication by means of a flashing lamp on the test console. At the same time, another panel lamp glows steadily, indicating the particular voltage that is out of tolerance.

Figure 12–7 is a simplified schematic, which indicates the method of selecting and checking the various voltages. The stepping switch applies the missile potentials to the monitoring circuits through T-networks made up of precision resistors. As shown in the drawing, a regulated voltage is also applied to the network to serve as a standard. Each contact of the stepping switch is connected to a different T-network, one being provided for each supply voltage to be checked.

The voltages indicated in figure 12–7 are typical values. A positive d-c missile potential of 310 volts is applied through

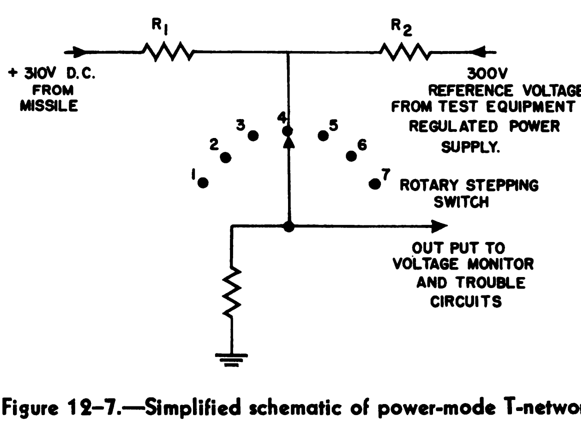

Figure 12–7.—Simplified schematic of power-mode T-network.

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R_1. A negative 300-volt reference is applied through R_2. The output of the T-network is taken from R_3 for application to the monitoring circuits. The values of R_1 and R_2 are such that, when the applied voltages are of the values shown, a voltage drop of 310 volts appears across R_1 and 300 volts is developed across R_2. In this case, the output voltage across R_3 is zero.

When the value of the missile voltage differs from the desired value of 310 volts positive, an output other than zero appears across R_3 and is applied to the monitoring circuits. If the missile voltage is out of the tolerance limits, circuits are activated which lock the stepping switch in the position corresponding to the voltage at fault. The trouble circuits are activated, and the indicator lamps on the test-console panel are turned on.

One of the important functions of the power-mode checks is protection of the missile circuits from the effects of incorrect voltages. It is the first mode of operation in the checkout procedure; and if trouble is detected in the missile power system, the test equipment removes all supply voltages except those applied to the vacuum-tube filaments. Also, the power mode can be initiated and repeated at any time during any of the other tests if it becomes necessary to recheck the supply voltages.

SYSTEMS MODE CHECKS.—In this mode, as in the power mode, the equipment provides high-speed checking by automatic programming and monitoring. Three classes of tests are performed: monitor checks, automatic-pilot tests, and guidance tests.

The MONITOR CHECK, the first of the tests, serves to insure that the automatic monitor circuits are functioning properly. These circuits are supplied with check voltages which are produced within the equipment. If the monitoring action is correct, the test runs to completion. If incorrect, the automatic programmer is halted and an indication is given the operator by means of a flashing light. The operator then takes steps to locate the cause of the malfunction, which must be corrected before proceeding with other tests.

In the AUTOMATIC-PILOT TEST, the equipment checks the

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components of the control system which guide the missile during the automatic-pilot phase of flight. Typical conditions encountered in actual flight are simulated by means of input signals derived by producing electrical unbalance in the output circuits of the missile instruments, the gyroscopes and accelerometers.

The control system responds to any one of these unbalanced conditions by making a certain wing deflection. The response is checked by the test equipment by monitoring the wing-feedback potentiometer output voltages which are determined by the position of the wings. These voltages are fed to the automatic monitors by the same process employed in the power-mode checks.

In the GUIDANCE TEST, the equipment performs a group of checks on the response of the guidance and control systems to simulated radar guidance signals. This series of tests checks the missile for proper operation during the time that it is guided in flight by the radar beam. The input test signals include rate gyro and micro wave signals simulating range, error, and beam position. The missile altitude is also simulated. As in the automatic-pilot test, the equipment monitors the wing-potentiometer voltages in checking the overall response to the various simulated conditions.

Manual Maintenance Checks

The manual maintenance mode of the checkout station shown in figure 12–6 enables the operator to localize a malfunction to a particular plug-in component of the missile system. When a circuit fault has been detected during the operational checkout, the operator may select a specific component for rapid check by means of manual selection and control of the type of input signals supplied to it. The outputs of the component resulting from the selected input conditions can then be observed to determine whether the component response is correct or inadequate.

The inputs to the component under test are signals which simulate flight conditions of the missile. Included in these are simulated displacement from boresight, range (distance from the aircraft radar antenna), lateral and normal accelera-

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tions (produced by accelerometer unbalance), changes in pitch and yaw attitudes, and rates of change in missile attitudes.

Provisions are made, not only for metering the outputs of the selected missile components, but also for measuring the power supplied to the missile units.

When the operator has determined the particular plug-in component which contains the malfunction, he replaces it with one from the supply of spares. After replacement of any component, a complete systems operational check must be made of the guidance and control systems of the missile.

Component Test Equipment

The specialized test equipment of each missile system includes various component test devices, each of which is designed for checking one of the individual units of the missile. Most component test sets are used for testing specific plug-in components, which are composed of complex electronic circuitry packaged as replaceable assemblies. Others are employed for testing items of simpler construction such as battery units (if these are used in the missile). Test sets for locating shorted or open leads in wiring harness are also provided in some missile systems.

TESTING PLUG-IN COMPONENTS.—Replaceable plug-in components are checked for proper operation before installation in missiles. A particular component may also be checked with appropriate component test equipment after it has given an indication of faulty operation during a manual maintenance check with the systems test equipment.

The component test set, in most cases, operates along the same lines as systems test equipment—it produces and applies signals to the input of the component which simulates conditions encountered in actual operation.

Consider, for example, a summing amplifier, which (as explained in a preceding chapter) sums stabilizing feedback voltages with pitch, yaw, and roll error signals and amplifies the resulting control signals. The test equipment designed for the amplifier provides the operator with a means of selecting various combinations of simulated error and stabilizing

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voltages. These are applied to the amplifier and the resulting outputs are checked either on panel-mounted meters or by means of external meters and other types of measuring instruments.

The complete test equipment for a specific plug-in component contains units of special design and also general-purpose instruments. The special equipment provides the required input signals and the power for operating the missile component during the test. The general-purpose instruments often used include oscilloscopes, voltmeters, and recorders of various kinds.

Figure 12–8 is a block diagram representing a typical setup for checking a plug-in component. The CONTROL UNIT and the HIGH-VOLTAGE POWER SUPPLY are the principal units supplied as special equipment. The former contains circuits for developing the test signals, the switches and controls for selecting and controlling the various inputs, and the jacks and connectors to which the general-purpose equipment is attached. The power supply unit provides high-voltage power both for the test equipment and for the component and also filament voltage for the tubes in the former.

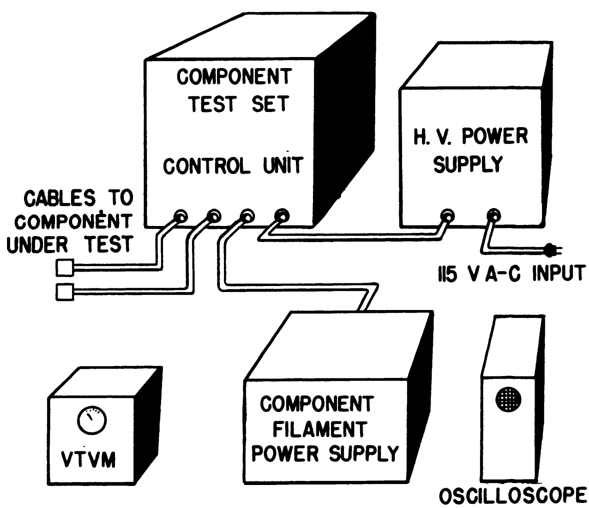

Figure 12–8.—Typical component test setup.

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The FILAMENT SUPPLY, which provides filament voltage for the component, is usually designed for use with more than one component and hence is not furnished as part of the special equipment. The VACUUM-TUBE VOLTMETER and OSCILLOSCOPE shown in figure 12–8 are instruments frequently used both in checkout and in troubleshooting procedures.

CHECKOUT PROCEDURES.—Component test sets are used in accordance with detailed procedures given in the equipment handbook. By means of the procedures, rapid checks can be performed, either to ascertain whether the component is operating properly or improperly, or to isolate the causes of trouble in case malfunctions are present.

The procedure consists of a series of operational steps. At each step, the handbook identifies the test points concerned; gives the required control positions and connections of the equipment; describes normal response of the component; and gives possible causes of abnormal indications to assist in locating defective parts.

In some cases, specific information is supplied by the handbook as to the causes of abnormal indications. The parts or subassemblies listed as possible sources of trouble can then either be replaced or checked by voltage or resistance measurements. Also, adjustments may be required; and if so, reference is made to the section of the handbook containing the proper adjustment procedure.

If specific information cannot be given, the handbook provides instructions for taking steps which isolate the trouble and lead to specific information. The steps consist of checks made at assigned check points.

Three types of test points are assigned in a unit to provide checks involving different amounts of circuit detail. MAJOR CHECK POINTS are usually located at output terminals of one or more stages so that many circuit elements are included between any two. These points are identified in the checkout procedures and on schematic diagrams by numbers in starred circles.

SECONDARY CHECK POINTS are located in the sequence of signal flow between major check points and are identified by capital letters inclosed in circles. MINOR CHECK POINTS,

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each identified by a capital letter and a number in a circle, are located between secondary check points.

The checkout procedure can be used either for testing the overall operation of the component or for locating defective parts. The suggested tests at the major check points are made first. If normal indications are obtained at each, the unit is operating satisfactorily and no further tests are required.

If an abnormal indication is obtained, the possible causes listed by the handbook are checked. If these are eliminated, then tests are made at the associated secondary check points as directed. Similarly, minor check points are passed over unless an abnormal indication is obtained at the related secondary check point. Trouble is thus isolated to a specific location within the unit. For wiring details and locations of parts, reference is made to the parts layout diagrams and component wiring diagrams in the maintenance handbook.

BATTERY TEST SETS.—As stated in chapter 10, in some missiles, battery units (often composed of four batteries) are used as primary sources of electrical power. The batteries must be tested prior to installation in the missile; and the only satisfactory test is to measure the terminal voltage of the unit under the same electrical load condition encountered in operation.

Battery test sets are in use which make this kind of test rapidly and accurately but automatic operation. A typical example of this class of test equipment is used according to the following general procedure:

The test set, which requires 115-volt a-c power, is plugged in, turned on, and allowed to warm up for 60 seconds. The battery unit is placed on a small movable platform, which is swung into position for testing by means of a handle. In this position, a multipin connector on the battery box is attached to a corresponding connector on the test set.

Two tests are performed, each initiated by pushbuttons: first a LOW and next a HIGH. Each test is terminated when a TEST COMPLETED panel lamp comes on. In both checks, the pointer of a panel-mounted meter gives indications of satisfactory or unsatisfactory battery condition. In the former

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case, the pointer remains in a green area on the meter dial for the duration of the check. The battery unit is rejected if the pointer fails to reach the green area or drops back from it before the TEST COMPLETED lamp comes on.

After the two checks have been completed, the handle is positioned so as to disconnect the battery unit, which is then ready for installation in the missile.

WIRING HARNESS TEST SETS.—Missile harness is composed of a number of wires formed into cables and terminated with suitable connectors. It is used to connect the major missile sections and also the plug-in components within the sections. The complete harness carries all the signal voltages and the electrical power required for missile operation.

It is not an uncommon occurrence for a wire to break or become shorted, either to another wire or to ground. When this happens, the cable must be checked and the defective wire repaired.

One method of locating faults in cables is by checking continuity between the pins of the connectors with an ohmmeter. For this, a wiring diagram is required to determine which pins normally show continuity. High-resistance shorts between conductors may be detected by the use of a MEGGER. Procedure with either of these instruments is a laborious and time-consuming process.

Harness test sets provide means for making cable checks by high-speed techniques. The connectors of the wiring harness are attached to mating plugs on the set. The equipment is connected to a 115-volt outlet, and the test is initiated by pressing a pushbutton.

The test set then steps automatically through a series of tests, checking a different wire at each step of the test cycle. A numerical dial indicates which wire is under test, stepping each time an individual check is completed.

The test sequence continues to completion unless a defective lead is detected. If this occurs, the test is halted and an indicator lamp comes on. The operator then notes the number shown on the test set dial and refers to a chart which accompanies the set. Opposite the number on the chart is

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the designation of the connector pin to which the defective lead is attached. After repair has been accomplished, a recheck of the harness is made. When the test set completes the full test cycle, the harness is shown to be in satisfactory condition.

GENERAL-PURPOSE TEST EQUIPMENT

In addition to specialized missile test devices, numerous types of general-purpose instruments are employed by the GF in checking, maintaining, and repairing missile components and related test equipment. These consist mainly of electronic and electrical test sets and meters; but many hand tools such as calipers, micrometers, and various kinds of gages are included in the missileman's list of standard equipment.

This section is concerned principally with the instruments used in electrical and electronic testing. It is intended for study in conjunction with three basic texts: *Basic Electricity*, NavPers 10086; *Basic Electronics*, NavPers 10087; and *Basic Hand Tool Skills*, NavPers 10085. The chapters of these books which supply the required information are referenced throughout the following pages.

The source of major importance is chapter 13, *Basic Electronics*, which discusses the principles and construction of many test devices used in the work of the GF, such as synchroscopes, electronic switches, impedance bridges, tube testers, and signal generators.

Electrical Indicating Instruments

The basic electrical indicating instruments are the voltmeter, the ohmmeter, and the ammeter. The first of these, the voltmeter, is a standard device in most missile measurements, being employed in troubleshooting, in calibration of test equipment, and in the setup procedures of many kinds of specialized missile test sets.

THE USE OF THE VOLTMETER.—*Basic Electricity*, chapter 9, contains the necessary information on the operating principles and construction of the d-c voltmeter and of the standard

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a-c meters, the electrodynamometer, and the iron-vane. Of these, the d-c voltmeter is the instrument most frequently used for localizing defects in missile components and in maintaining test equipment.

Voltage measurements are made at various points in the stage or stages suspected of being at fault. The observed voltage values are then compared with the normal values given in the appropriate *Handbook of Service Instructions*, and from the comparison the defect can usually be isolated.

Voltage checks are most effective when applied within a single stage after previous checks have been made to localize the fault as closely as possible. This is particularly true with complex missile electronic circuits, since any attempt to measure all the voltages present in most of these would be a very time-consuming process.

It is important that the voltmeter used in checking defective components conforms to the specifications listed in the equipment handbook. The meter should have the same SENSITIVITY as that used by the manufacturer in making the original voltage measurements; otherwise the values observed may not match the standard values. As explained in the basic text, meter sensitivity is rated in ohms per volt, or the total resistance of the meter and dropping resistor divided by the voltage required for full-scale deflection. The higher the sensitivity, the lower the current drain through the meter, and the greater the accuracy of the measurement.

When setting up or calibrating missile test equipment, various a-c and d-c voltages must be adjusted to specified standard values. In these procedures, electronic voltmeters (also called vacuum-tube voltmeters) are usually required. Compared with a standard voltmeter, an instrument of this type has the advantage of greater input impedance. Hence, it introduces less error due to changes made in circuit operation when the meter is applied. The theory of operation of a representative meter of this class is given in *Basic Electronics*, chapter 13.

RESISTANCE CHECKS.—The ohmmeter is the basic instrument used to determine the resistance of a circuit or a circuit

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element. The theory and construction of the series-type and the shunt-type ohmmeters are discussed in *Basic Electricity*, chapter 9, which also describes a more specialized type of instrument, the megohmmeter, or megger.

The use of resistance checks for locating defective parts in electronic circuits is somewhat similar to the process of voltage checking, except that the equipment must be switched off and the suspected parts measured with an ohmmeter. The observed resistance values are then compared with the normal values given in the equipment handbook in order to identify the malfunctioning part. This method, like voltage checking, is most effective after the trouble has been isolated to a single stage.

Tests made to determine continuity or shorts in electric cables are typical examples of routine uses of the ohmmeter. The megger is also employed for testing cables. It contains a source of fairly high voltage (usually a hand-powered generator) which is applied to the cable in order to test it under conditions approximating those of operation. It is used principally for detecting high-resistance shorts and for measuring leakage in insulation.

Current measurements.—The principal classes of current-measuring devices, both d-c and a-c, are described in chapter 9, *Basic Electricity*.

The ammeters used in missile systems test equipment and component test sets are usually panel-mounted instruments. In these applications, they indicate the current drain of the major electrical circuits and thus provide a valuable first step in finding trouble. When ammeters are not included as parts of the equipment, current measurements can be made only after the circuit wiring has been opened and the meter inserted in series with the part in question. This is often a time-consuming procedure, and therefore, voltage or resistance checks are usually preferable.

The Cathode-Ray Oscilloscope

The cathode-ray oscilloscope is one of the most useful and versatile of test instruments. It is essentially a device for displaying graphs of rapidly changing voltage or current,

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but it is also capable of giving information concerning frequencies, phase differences, and voltage amplitudes.

The oscilloscope is used to trace test signals through missile receivers and video amplifiers, to measure percentages of modulation in missile test equipment signal simulators, and to localize the sources of distortion in test equipment and in missile components. It is used to measure peak a-c and r-f voltages, to measure video-amplifier gain, to make overall frequency response curves, and to study dynamic tube characteristic curves.

These are but a few of its many applications. The discussion here is confined to some of its uses in measurement and maintenance of electronic equipment. For a coverage of the theory of the cathode-ray tube and of the basic circuits and controls of the instrument, the reader is referred to *Basic Electronics*, NavPers 10087, chapter 13.

THE AN/USM–24 OSCILLOSCOPE.—Missiles employing radar guidance respond to pulses which have distinctive waveforms, spacing, and timing. When observing these signals while testing the missile units and adjusting the associated test equipment, it is necessary to have an oscilloscope with features which make it suitable for pulse displays. A typical instrument of this type is the AN/USM–24, which is shown in figure 12–9. It is capable of presenting square-wave signals with small amounts of distortion and has self-contained means of measuring pulse duration, spacing, and amplitude.

Since it is usually desirable to observe the amplitudes of signals with respect to time, the AN/USM–24 provides horizontal sweep voltages which vary linearly and serve as the time base. The horizontal deflection system can be operated either in periodic fashion or it may be set to give synchroscope operation, in which a sweep of short duration is generated only when a synchronizing signal is present.

By means of a SWEEP switch and a FINE-SWEEP potentiometer, the time base may be varied within the limits of 1.25 and 125,000 microseconds. Also, any portion of the time base over 10 microseconds in duration can be selected and expanded for more detailed observation of the signal.

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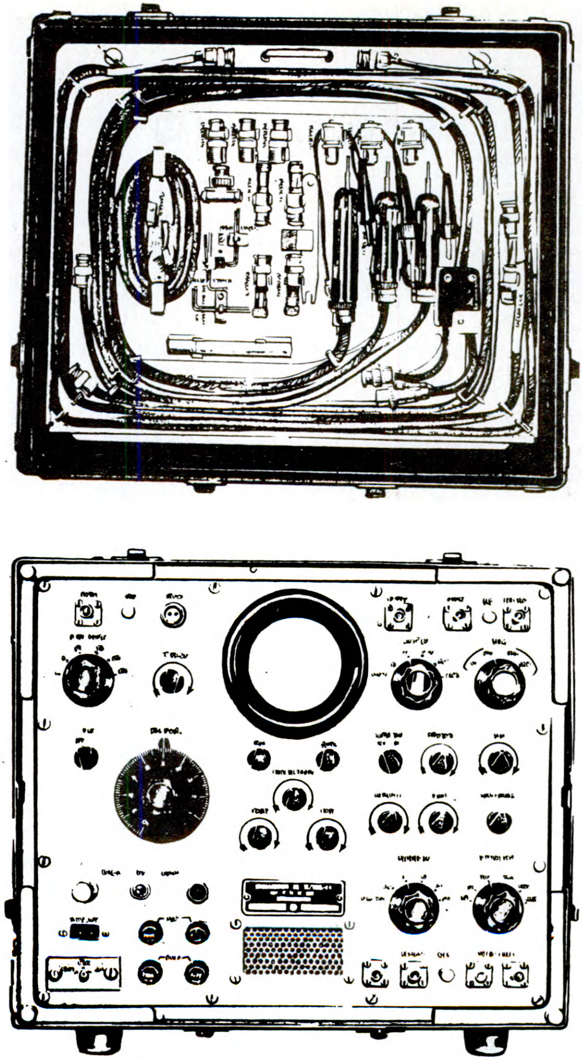

Figure 12–9.—The AN/USM–24 Oscilloscope.

The signal amplifiers respond uniformly over a wide frequency band so that flat-topped pulses are displayed with minimum distortion. The signals are presented as vertical deflections; and the sensitivity of the vertical amplifiers is

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such that those with amplitudes from 0.01 to 150 volts can be observed directly.

Two types of test probes are supplied as accessories. One enables the operator to observe signals ranging in amplitude from 150 to 600 volts. The other is used for signals up to 2 volts in amplitude when low amounts of shunt-capacitance loading are required. The vertical channel includes a delay line (with 0.055-microsecond delay) which makes it possible to observe the leading edges of pulses triggering the horizontal sweep circuits.

The time duration of signals or portions of signals displayed may be measured by means of accurately timed marker pulses, which appear as intensified dots along the trace. The marker pulses are generated internally at five fixed repetition rates: 0.2, 1, 10, 100, and 500 microseconds. For measurment of time durations less than the marker intervals, the horizontal length of the trace can be varied by means of the horizontal-gain control. This permits interpolation between the markers by use of the grid on the screen.

For observation of high-speed transient voltages, the linear time base produces a gate which intensifies the electron beam during the "go" time only, thus producing traces with high intensity without injury to the screen of the cathode-ray tube.

All operating controls and connectors are either placed on the front panel or else are accessible through the ventilating door on the rear of the case. All accessories are mounted on a tray on the oscilloscope cover. The controls and connectors are arranged functionally and are labeled so that the instrument can be operated without reference to the instruction manual.

Precision Frequency Measurements

The discussion of frequency measuring equipment in the following pages should be studied in connection with the section entitled "Frequency Standards" in chapter 13, *Basic Electronics*, NavPers 10087.

HETERODYNE FREQUENCY STANDARDS.—As explained in the basic text, a secondary frequency standard is an instru-

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ment used to produce signals of known frequency for use in tuning transmitters, in calibrating field strength meters, and for adjusting the tuning circuits of receivers and other types of tuned r-f equipment.

The term FREQUENCY METER is often applied both to instruments of the heterodyne type and to those which merely measure the frequencies of externally produced signals by means of calibrated tuning circuits. The latter instruments are more properly called WAVEMETERS. A heterodyne frequency meter can be used as a signal generator for supplying accurate test signals of moderate amplitude. It can also be used as a wavemeter for measuring the output frequencies of transmitters and other types of emitters.

A frequency standard of the heterodyne type contains a crystal-controlled oscillator used as a reference. An adjustable oscillator provides the output signals after being calibrated against the reference oscillator. In addition, a typical instrument of this class usually contains an r-f harmonic (or distortion) amplifier, a mixer, a modulator, an audio-frequency amplifier, and some means of providing an indication of "beat frequencies" such as a meter or headphones. Most frequency meters are used with a set of calibration charts giving the dial reading of the frequencies produced, together with a table of crystal harmonic frequencies for calibration purposes. The chart provides a complete and accurate coverage of the operating range of the instrument.

Heterodyne frequency standards and wavemeters are used in the work of the GF. His duties require, in addition, that he use instruments of more elaborate design which are capable of measuring numbers of random pulses as well as the frequencies of periodic waves.

Frequency Meter AN/USM–26

The AN/USM–26 is a precision laboratory instrument designed for measurements of frequency, time intervals, periods, frequency ratios, and "total events." The capabilities of the instrument are such that it may be used as a secondary frequency standard when calibrated regularly by a fairly simple method.

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The complete equipment consists of the FR-38A/U Frequency Meter and two plug-in units, only one of which is used at any one time. The appearance of the control panel of the FR-38A/U is shown in figure 12-10. This unit contains the counting and gating circuits upon which the operation of the instrument largely depends. The plug-in units are designed to perform separate functions, but either may be used to measure unknown frequencies up to 10 megacycles per second.

One of the plug-in units, the MX-1636/U, the Time Interval Unit, contains attenuator and trigger circuits used in the measurement of time intervals. The other, the MX-1637/U, is the Frequency Converter Unit, which mixes the proper harmonic frequency of a standard signal with the unknown frequency to be measured. The converter equipment is employed for frequency measurements above 10.1 mc.

Basic operation.—Unlike more familiar frequency meters, the FR-38A/U counts, cycle by cycle, the variations in the signals fed into it from the plug-in unit in use. The frequency meter contains no tuned circuits in the path of signal flow; hence, the incoming signals need not be periodic, but may have the random character of the output of the Geiger counter.

In measuring frequency, counting circuits in the principal unit count the number of pulses occurring during an interval of time determined by an internal oscillator. An indication of the average number of "events" or signal variations taking place during the interval is made by means of two meters and several etched numeral plates mounted on the panel. The counting operation is repeated automatically, each cycle of counting lasting for the interval of time determined by the time-base oscillator.

A simplified block diagram showing the principal units required in the frequency function of the instrument is given in figure 12-11. The equipment consists principally of a digital counter into which the signals to be measured are fed through a signal gate. The gate is opened by the time-base generator to permit application of the signal to the counters. After a very accurately determined interval of

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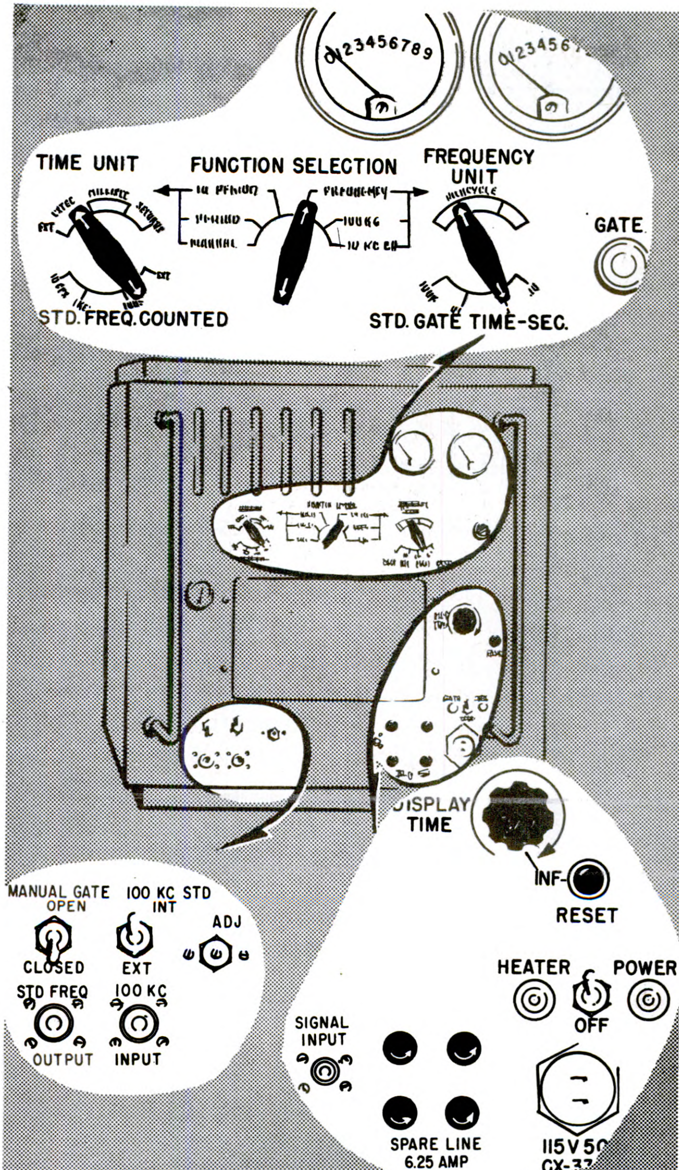

Figure 12-10.—Front-panel controls of FR-38A/U Frequency Meter.

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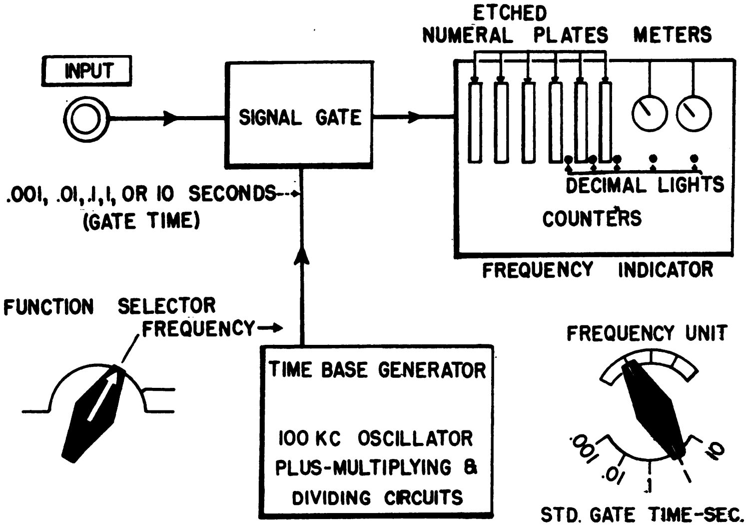

Figure 12-11.—Simplified block diagram: AN/USM-26, frequency function.

time, the gate is closed until the start of another cycle of counting.

The gate times, or counting intervals, are integral powers of 10 times 1 second, ranging in value from 0.001 to 10 seconds. An illuminated decimal point on the front panel shifts according to the gate time selected so that the meter always reads directly in kilocycles.

In addition to the frequency function, the FR-38A/U has provisions for measuring the period of the applied signal (reciprocal of frequency) and for determining accurately the time interval between two signal events. A summary of the capabilities of the complete set is given in table 12-1.

As may be seen in the table, the accuracy of the frequency meter is dependent upon the accuracy of calibration of the internal standard oscillator and also upon an error of 1 count, which is inherent in the signal-gate circuit used. The oscillator operates at 100 kilocycles with a normal drift of no more than 2 parts per million per week. However, the percentage of error with signals below 10 kilocycles increases rapidly because of the error in the signal-gate circuit.

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Table 12-1.—Specifications for Frequency Meter AN/USM-26.

FREQUENCY MEASUREMENT	
Range	10 c. p. s. to 100 mc. (direct reading).
Accuracy	± 1 count ±0.0002 percent* (±0.1 c. p. s. ±0.0002 percent on 10-second gate).
Gate Time	0.001, 0.01, 0.1, 1, or 10 seconds; selected by panel control.
Display Time	Continuously variable from 0.3 to 5 seconds by a panel control. In manual operation, display time continues until reset.
PERIOD MEASUREMENT	
Range	0.01 c. p. s. to 10 kc. (100 microseconds).
Accuracy	±0.03 percent.
Gate Time	Counts for 1 or 10 cycles of input signal as desired.
Units of Measurement	0.1 microsecond, 0.01 millisecond, 1 millisecond, or 0.1 second.
Display Time	Same as for Frequency Measurement.
TIME INTERVAL MEASUREMENT	
Range	1.0 microsecond to 10,000,000 seconds.
Accuracy	±0.1 microsecond ±0.0002 percent.*
Independent Start and Stop Channels.	Triggers from either positive- or negative-going input voltages at levels from −200 to +200 volts. Separate or common direct-coupled inputs.
Display Time	Same as for Frequency Measurement.

*Internal Standard. The accuracy figure of 0.0002 percent is due to the internal crystal oscillator, which has a long time stability of within two parts/million/week. Short time stability is within one part/million. A panel connector permits use of an external 100 kc. primary standard signal to obtain higher accuracy.

When measuring signals below 316 kilocycles, greater accuracy is obtained by determining the period of the wave than can be obtained by direct frequency measurement. The meter has provisions for measuring the period, or the average value of 10 periods, of signals ranging in frequency down to 0.01 cycle per second. Below this frequency, the time interval unit can be used to measure periods as long as 10 million seconds (approximately 1,175 days).

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Wavemeters

Wavemeters consist essentially of tuning circuits calibrated for measuring frequency. Although the accuracy of the typical wavemeter is not as high as that of heterodyne frequency meters, these instruments have the advantage of comparative simplicity and most can be carried about easily.

Many types of tuning circuits are used in wavemeter applications; the exact kind of circuit employed depends largely upon the frequency range of the instrument. Resonant circuits consisting of coils and capacitors are used in low-frequency wavemeters. Butterfly circuits, adjustable sections of transmission line, and resonant cavities are used in VHF and microwave instruments.

There are three basic kinds of wavemeters: the absorption, the reaction, and the transmission types. An absorption meter is composed of a tuning circuit, a rectifier, and a meter for indicating the amount of current induced into the wavemeter. In use, this type is loosely coupled to the circuit to be measured; and the tuning circuit of the wavemeter is then adjusted until the current indicator shows maximum deflection. The frequency of the circuit under test is then read on the calibrated dial of the wavemeter.

The reaction type derives its name from the fact that it is adjusted until a marked reaction occurs in the circuit measured. For example, the wavemeter is loosely coupled to the grid circuit of a low-frequency oscillator. The meter is adjusted for resonance with the oscillator frequency. The setting of the wavemeter dial can be made by observing the grid-current meter of the oscillator. At resonance, the wavemeter takes energy from the oscillator, causing the grid current to dip sharply. The frequency of the oscillator is then determined from the dial of the wavemeter.

The transmission wavemeter is an adjustable coupling link. When it is inserted between a source of radio-frequency energy and an indicator, energy is transferred to the indicator only when the wavemeter is tuned to the source frequency to

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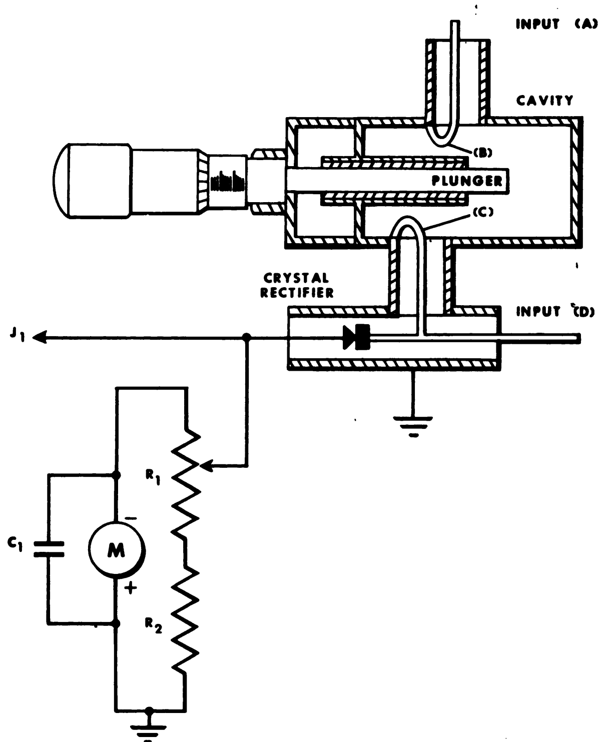

Figure 12–12.—Typical cavity wavemeter.

be measured. The value of this frequency is then determined by calibration data suitable for the particular wavemeter.

Transmission wavemeters are widely used for measuring microwave frequencies. The example illustrated in figure 12–12 contains a tunable cavity which serves as the necessary frequency-selective element. The resonant frequency of the cavity can be varied by means of a plunger that is mechanically connected to a micrometer mechanism. Movement of the plunger into the cavity effectively reduces the cavity size and increases the value of the resonant frequency; withdrawing the plunger causes the cavity to resonate at a lower frequency.

Microwave energy from the equipment under test is fed

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into the wavemeter through one of the two inputs, (A) or (D), shown in figure 12–12. The signal is rectified by a crystal circuit and the amplitude of the resulting current is is indicated on the current meter, M.

The instrument can be used either as a transmission or as an absorption meter. In the former case, the signal to be measured is coupled into the circuit by input (A) and out through loop (C) to the crystal rectifier. The cavity adjusting plunger is set for a maximum reading of the current meter. The micrometer reading at this setting is then used with a calibration chart, supplied with the meter, to determine the unknown frequency.

When the source signal to be measured is relatively weak, such as that of a klystron oscillator, the wavemeter is usually employed as an absorption instrument. Connection to the wavemeter is made at input (D), and the r-f loop (C) then functions as an injection loop to the cavity. When the cavity is tuned to resonance with the source signal, the current indicated on the meter dips. Off-resonance settings of the cavity result in high values of rectified current; hence, the plunger adjustment is varied until the meter reads a minimum value. The frequency can then be determined from the micrometer reading and the calibration chart.

The potentiometer, R_1, (fig. 12–12) is used to adjust the meter sensitivity. The video jack, J_1, is provided for observing video waveforms when the instrument is employed in conjunction with a test oscilloscope.

Spectrum Analyzers

When a radio-frequency carrier wave is modulated by keying, by speech waveforms, or by pulses, the resulting wave contains many frequencies. The original carrier frequency is present, together with two groups of new frequency components called SIDEBANDS. One group of sidebands is displaced in frequency below the carrier. The other group consists of sidebands greater in frequency than the carrier. The distribution of these frequencies, when shown on a graph of voltage or power versus frequency, is called the SPECTRUM of the wave.

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Spectrum analyzers are electronic test instruments used to provide visual indications of the frequency components present in modulated waves and in other complex signals. For introductory material on these instruments, the trainee is referred to chapter 13, *Basic Electronics*, NavPers 10087. The basic text discusses the fundamental operating principles, provides a block diagram, and describes a representative example of this type of instrument.

Spectrum analyzers are employed extensively for checking the outputs of transmitting tubes such as magnetrons, which are used in pulse radar systems. In this kind of analysis, unwanted effects such as frequency modulation of the carrier wave can be easily detected. In pure amplitude modulation by square pulses, the spectrum is symmetrical about the carrier frequency. Lack of symmetry indicates the presence of frequency modulation.

A spectrum representing correct operation is shown in (A) of figure 12–13. Examples of undesirable magnetron spectra are shown in (B) and (C). The latter indicate trouble in the modulator, the tuning system, or in the magnetron tube.

The carrier frequency is best defined as the center frequency in a symmetrical spectrum such as that shown in (A) of figure 12–13. In some spectrum analyzers, this fact serves as the basis for measuring the frequency of the carrier wave. A highly selective tuning circuit is provided in the receiver section of the instrument to function as a trap, which prevents a very narrow band of frequencies from appearing in the display. As a result of its use, a narrow gap appears in the spectrum corresponding to the frequency to which it is

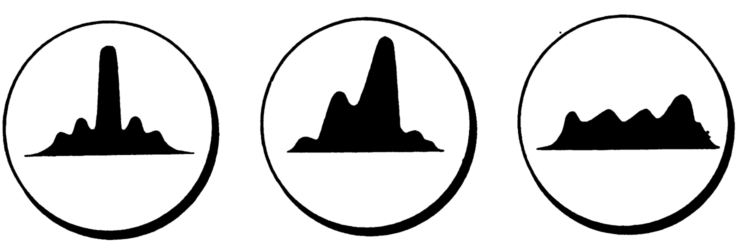

Figure 12–13.—Frequency spectra.

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tuned. The tuning adjustment of the trap is calibrated; and when the gap is made to appear in the center of the spectrum, the carrier frequency can be determined from the tuning dial of the trap.

Testing Crystal Rectifiers

The function of a crystal rectifier test set is to provide a quick and accurate means of testing a crystal rectifier in the field. Although the complete testing of a crystal rectifier is an elaborate procedure requiring precision radio-frequency test equipment, the test sets usually provided are sufficient for determining whether or not the crystal is satisfactory for use. Crystal testing is accomplished by measurement of the forward and backward resistance and the back current at 1.0 volt.

A crystal rectifier is a device used for converting r-f energy into unidirectional current. It usually consists of a small piece of silicon in contact with a thin tungsten wire (called a cat whisker), both of which are mounted in a small cartridge-type container. The rectification takes place at the contact between the silicon crystal and cat whisker, and is due to the fact that the resistance in one direction is greater than that in the other direction (as in a vacuum tube used as a rectifier or detector). The properties of the rectifier depend critically on the type of contact area and the place of contact. The crystal rectifier has been carefully adjusted at the factory, and should not be upset by tampering with the setscrew.

A crystal rectifier is illustrated in figure 12–14. The crystal is designed so that current normally flows from the tip to the base (tungsten to silicon). The area of contact within the crystal rectifier housing is very small, and if too much current is passed through the cartridge, the resulting heat will damage it, causing the operation of the crystal rectifier to be impaired or the unit to burn out completely.

Crystal rectifiers may be damaged by static discharges. The operator should be sure that any static charge which may be present on the body is discharged by momentarily touching (grounding) a finger to the ground contact of the test set or equipment in which the crystal is to be installed.

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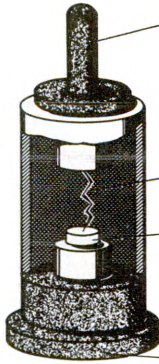

Figure 12–14.—Crystal rectifier.

Because of the possibility of damage due to strong r-f fields which may be present, crystals are stowed in metal containers or in metal foil except when they are being tested or used.

The circuit diagrams of a typical crystal rectifier test set are illustrated in figures 12–15 and 12–16. The figures show two arrangements of the same device. The test set can be changed from the resistance measuring arrangement to the back-current measuring circuit by the action of a selector switch. The meter shown in the two figures is calibrated for both resistance and current measurements. It contains a 0–1 milliampere movement with an internal resistance of approximately 100 ohms.

The circuit shown in figure 12–15 is used for forward and backward resistance measurement and is similar to the circuit of a simple ohmmeter. With switch S1 set to the ZERO ADJUST position, the milliammeter is first set for maximum (1.0 ma.) current, or zero indicated resistance, by adjustment of the series potentiometer R_{102}. The forward or backward resistance can then be measured by rotating S1 to the appropriate position and placing the crystal rectifier in the proper holder.

If no further change has been made in the position of the control R_{102}, the additional resistance which the crystal rectifier introduces into the circuit causes a decrease in the

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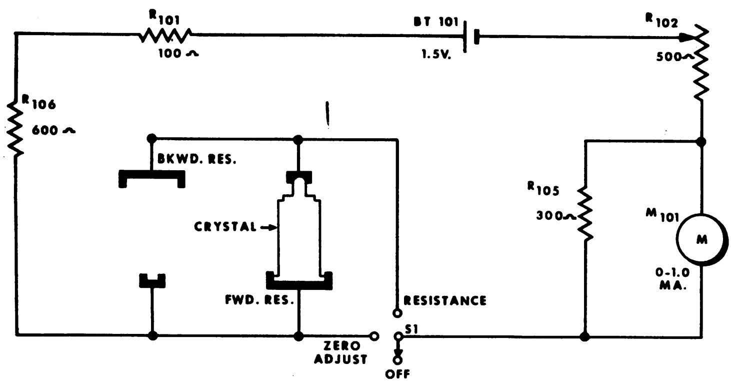

Figure 12–15.—Rectifier test set schematic—resistance measurement.

current flow, and the meter will then deflect to some point on the scale other than the full deflection.

The forward, or "front," resistance of the crystal is the resistance measured with normal current flowing (comparable to the cathode-to-plate current flow in a diode vacuum tube). The crystal rectifier is considered unfit for use if this resistance is greater than 500 ohms.

The backward, or "back," resistance of the crystal is a measure of resistance to current flow from the crystal to the whisker of the rectifier. This current flows from the rectifier base to the tip and is comparable to any current flowing from the plate to the cathode in a diode vacuum tube. The crystal rectifier should be rejected for use if the ratio of back resistance to front resistance is less than 10 to 1.

For example, if the meter reading is 400 ohms when the forward resistance is measured, then the back resistance must be at least 4,000 ohms or more, if the crystal is to be considered usable.

In addition to the circuit arrangement for checking the resistance ratio of the crystal rectifier, many test sets are provided with a means of measuring the back current through the rectifier with an applied voltage of 1.0 volt. This is a more accurate measure of the condition of the crystal than the resistance-ratio check. The circuit arrangements for this check are illustrated in figure 12–16. In (A)

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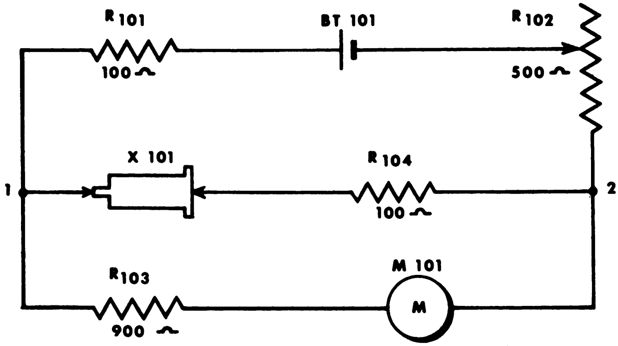
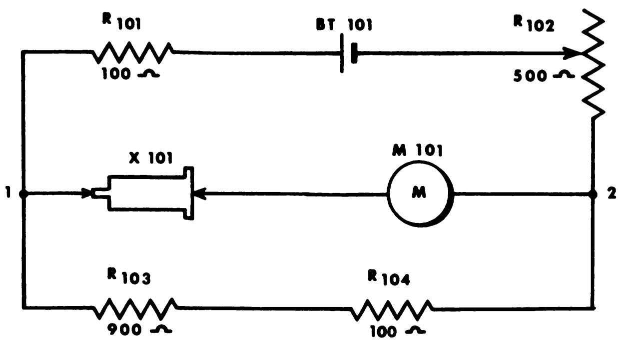


(A) BACK CURRENT ZERO ADJUSTMENT



(B) BACK CURRENT

Figure 12–16.—Rectifier test set schematic—back current measurement.

of the figure, the circuit is shown in the condition used for the initial voltage adjustment.

Before the back current is measured, the meter must be adjusted so that an effective voltage of 1.0 volt is impressed across points 1 and 2. Since the back resistance of a crystal rectifier is a high value, the effective resistance of the parallel circuit between points 1 and 2 in (A) of the figure is essentially that of the meter and R_{102}, or 1,000 ohms. The full-scale reading of the milliammeter is 1.0 milliampere; therefore, an adjustment of R_{102} resulting in full-scale deflection of the meter insures a voltage of 1.0 volt across the parallel circuit.

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After the voltage has been adjusted, the circuit is switched to the condition shown in (B) of figure 12–16 to measure the back current. In this condition, the position of the crystal rectifier and R_{103} are exchanged so that the crystal is now in series with the milliammeter which has negligible resistance compared with that of the rectifier. With 1.0 volt impressed across this circuit, the meter then indicates the current flowing through the crystal rectifier. The magnitude of this current is inversely proportional to the backward resistance of the crystal. The scale of the meter is usually marked to indicate the maximum limits of back current for the crystal rectifiers in common use.

The maximum allowable back current varies somewhat with temperature. The lower the temperature, the lower the maximum limit of back current. Temperature correction tables are included with the instruction manuals of most test sets. These should be consulted when the surrounding temperature is considerably lower or higher than 70° F. (approximately 22° C.).

R-F Power Measurements

In the initial setup procedures of certain missile test equipment (both systems test and component test sets), it is necessary to measure and adjust the power of microwave signals. For example, with radar-signal simulating equipment, the test signal supplied in one phase of the checkout is required to be of a specified power value in order to serve as a reference.

The missile response is checked first with inputs set to the reference value, which represents the radar energy received at a particular range. Signal power is then progressively reduced by inserting known values of attenuation in the source, thereby simulating signals received at greater ranges. It is important that the reference power be set accurately; and to accomplish this, it is usually measured by means of an instrument containing a heat-sensitive element called a BOLOMETER.

POWER MEASUREMENT WITH BOLOMETERS.—The bolometer method of r-f power measurement is based on the detection

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of changes in resistance caused by changes in temperature. The bolometer element is mounted so that it is heated by absorption of r-f energy. The resulting change in resistance serves as a measure of the signal power, which is determined by means of an auxiliary bridge circuit, in which the bolometer forms one of the arms.

The principal components in bolometer measurements are the mount; the bridge; and the bolometer element, which may be any one of several types. The bolometer element is placed in the mount, which couples the r-f energy to it. Bolometer mounts must be specially designed for particular applications, and in microwave measurements they are composed of waveguide elements. The mount matches the impedance of the bolometer to that of the source; and in measurements involving large amounts of power, they are used in conjunction with directional couplers and attenuators which reduce the energy applied to the bolometer to suitable levels.

The bolometer bridge circuit is a special form of the Wheatstone bridge discussed in chapters 5 and 16, *Basic Electricity*, NavPers 10086. It can be used for measurements in different systems and is often supplied in test-set form, an example of which is given in figure 12–17. The figure shows the front-panel appearance of Test Set TS–147/UP, which

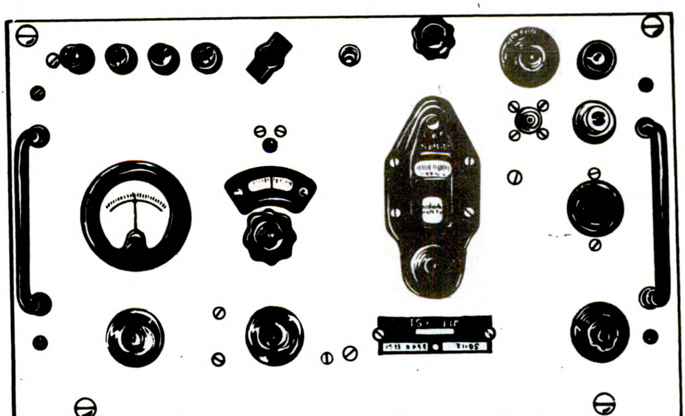

Figure 12–17.—Test Set TS–147/UP.

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contains a bridge of the balanced type described in this section.

Bolometers (as stated in chapter 4 of this course) are of two major kinds: barretters and thermistors. Barretters are normal resistive elements with positive temperature coefficients; that is, the resistance values increase with increases in temperature. In simplest form, they consist of short lengths of wire; and most have the desirable characteristic of operating effectively at comparatively high temperatures.

Thermistors are composed of metallic oxides. They have negative temperature coefficients (decreasing resistance with increasing temperature) of large value and may easily vary from 50 to 100 ohms for each milliwatt change in applied r-f power. Compared with barretters, thermistors have the disadvantage of operating at fairly low temperatures; therefore, they are more subject to error due to changes in surrounding temperature. As a result, instruments containing them must usually be compensated for ambient temperature variations.

Thermistor types.—There are two basic types of thermistors, both of which are used in the TS–147/UP. These are the bead type, illustrated in (A) of figure 12–18, and the disk type, shown in (B). The former consists of a semiconducting material mounted between two platinum-iridium wires and enclosed in a glass envelope. The semiconductor is generally a combination of the oxides of manganese and of nickel, to which a small amount of copper is added to increase the conductivity. Bead thermistors are frequently used as power-sensitive elements in microwave measurements. They are very small in size and do not give rise to large skin-effect errors which are present in some r-f thermocouple instruments.

The disk thermistor (fig. 12–18) has greater volume than the bead type and also more surface area. It is not used as a sensitive element in power measurements but is employed principally as a device for compensating for temperature and drift errors in bridge circuits. The resistance of the disk thermistor is relatively unaffected by current flowing through it and is dependent mainly upon ambient temperature.

Thermistor bridge circuits.—The bridges used for r-f

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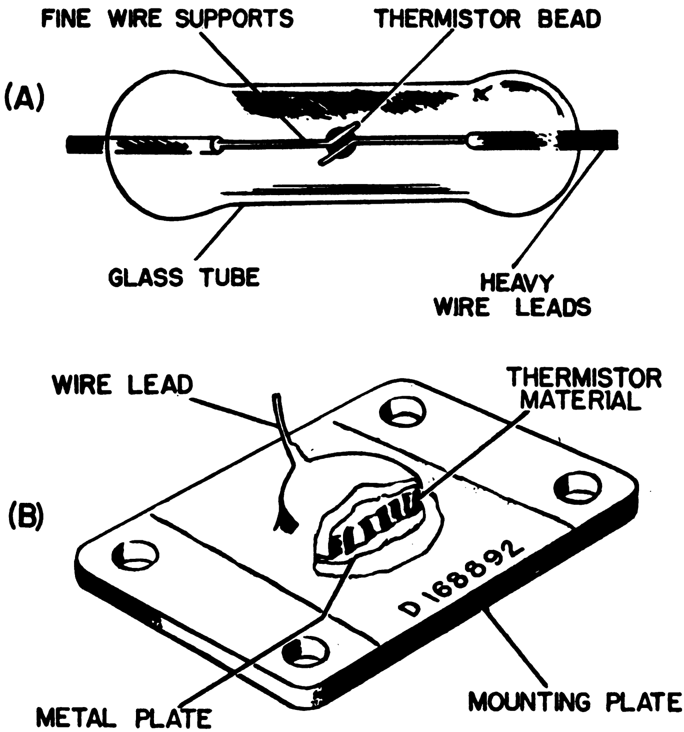

Figure 12–18.—(A) Bead thermistor; (B) disk-type thermistor.

power measurements are of two fundamental types, each of which has many variations. In the operation of one type, the BALANCED BRIDGE, the circuit is first unbalanced and is then brought into electrical balance by application of the r-f power. The value of the power is determined from the adjustments required to achieve the balanced condition.

The other type, the UNBALANCED BRIDGE, operates in the opposite manner. The bridge is balanced prior to applying the r-f energy. The amount of unbalance caused by the unknown power is then a measure of its value, which is usually read directly on a calibrated meter in the bridge circuit.

A source of variable control power is required with both types of bridges to set up the necessary initial conditions of

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balance or unbalance. This may be a battery equipped with a potentiometer or else a combination of a battery and a low-frequency, a-c supply.

The principle of balanced-bridge measurements can be illustrated by the circuit shown in figure 12–19. The bridge is composed of three fixed resistors and the variable-resistance thermistor. It is first unbalanced by a fixed amount when d-c power is applied through potentiometer R123. The amount of unbalance is such that exactly 1 milliwatt of r-f power must be applied to the thermistor to balance the bridge. The unknown power is then applied through calibrated attenuators, which are adjusted until the bridge is brought into balance. The value of the unknown power is determined from the amount of attenuation necessary to reduce it to the reference value of 1 milliwatt.

The bridge circuit (fig. 12–19) is balanced when the resistance of the thermistor meets the following condition:

$$\text{Thermistor resistance} = \text{R115} \times \frac{\text{R119}}{\text{R116}}.$$

In this condition, the current flow in the meter is zero, indicated by the pointer in the center-scale position of the dial marked Set Power.

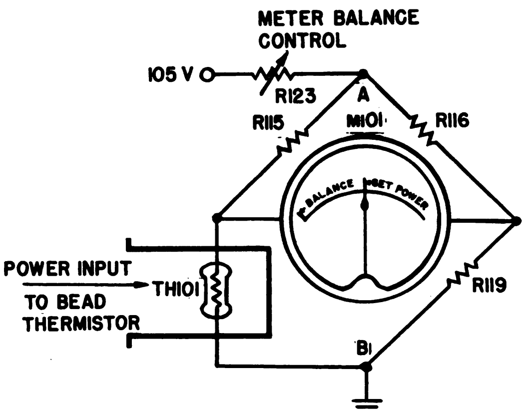

Figure 12–19.—Simplified balanced bridge.

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Many power-measuring sets used with naval equipment contain thermistor bridges of the unbalanced type, an example of which is given in figure 12–20. The figure shows a typical thermistor mount. In addition, the circuit contains two disk thermistors, TH–2 and TH–3, used to compensate for variations in ambient temperature.

TH–2 provides sensitivity compensation, the effect of which is to maintain the bridge sensitivity constant over a wide range of temperature. TH–3 is used for zero-drift compensation, which eliminates the necessity for frequent resetting of the potentiometer which applies the d-c power for initial balance of the bridge. Both types of compensation are employed in most thermistor instruments.

The accuracy of power bridges is affected somewhat by frequency. For this reason, it is desirable to make calibration checks and all necessary adjustments with the applied frequency as near as possible to that of the specific equipment to be measured.

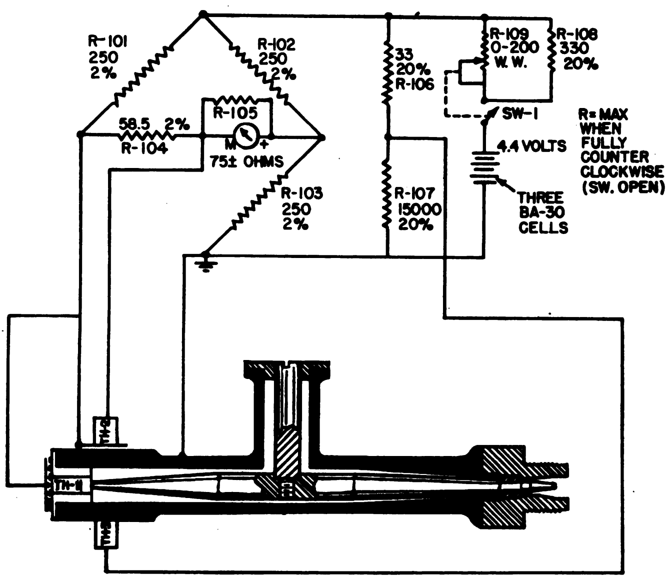

Figure 12–20.—Thermistor bridge: unbalanced type.

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Micrometers and Gages

The work of the GF involves the use of hand tools of special design as well as standard tools employed in many types of measurements. An example of the special-purpose type is the CLINOMETER, an instrument equipped with a leveling device which is used for measuring values of the angle made by a surface and a reference plane. Various kinds of clinometers are employed for checking and adjusting missile control surfaces such as fins, elevons, trim tabs, and wings. Because of the differences in airframe configurations of different missiles, each of these instruments must be used in accordance with instructions appropriate for the particular measurement involved.

Less specialized measuring tools are also required in the everyday duties of the missileman. At various times, modifications of missile units and assemblies must be made; and the layouts must conform exactly to specifications given in the prints or drawings accompaning the modification orders. Among the measuring tools used in most cases is the ordinary decimal rule; while vernier calipers may be required for more precise measurements.

Thickness gages are needed for may adjustments made in hydraulic and pneumatic units. For example, when repairing a hydraulic servo system, this type of tool is necessary for operations such as setting the travel distance of valves, which in typical cases are adjusted to tolerances of 0.005 ± 0.002 inches.

The types and uses of venier calipers, micrometer calipers, thickness gages, and most of the basic measuring tools used in missile work are discussed in section 1, *Basic Hand Tool Skills*, NavPers 10085. Sections 2, 3, and 4 of the text give further discussion of measuring tools as well as other standard hand tools the GF uses at various times.

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QUIZ

1. The term HANDLING, when applied to a missile system, refers to the procedures and steps taken with missile components
   a. only when they are being moved or tested
   b. only when being assembled or disassembled
   c. to insure that repairs and changes are properly logged
   d. from original issue through assembly and expenditure of the weapon

2. In the missile logistics pattern, a naval air station designated to provide missile logistic support for surrounding areas is supplied with equipment from two major sources, which are
   a. guidance and control sections from the manufacturer; ordnance units from naval ammunition depots
   b. guidance sections through BuShips; ordnance units directly from the manufacturer
   c. control sections and ordnance units from the nearest FASRon; spare components from GMAU's
   d. complete missiles from naval ammunition depots; spare parts from the manufacturer

3. On a naval air station designated to provide missile logistic support to surrounding areas, missiles are designated as ready for issue by the
   a. NAS Supply Department
   b. NAS Ordnance Division
   c. Guided Missile Service Unit
   d. supporting FASRon

4. The primary repair function of a Guided Missile Augmenting Unit is the
   a. overhaul of the missile control and guidance systems
   b. replacement of faulty components with new plug-in assemblies
   c. repair of fuses and ordnance equipment for the missile
   d. overhaul of the systems and components test equipment

5. When missile items are received by a using activity, they are first
   a. unpacked and stored until operational checks can be performed
   b. logged in and stored until they are to be used
   c. inventoried and inspected for apparent physical damage
   d. assembled and given a complete systems check

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6. The missile systems for which "in-package" testing is exceptionally well suited are those employing
   a. radar guidance systems and proximity type fuses
   b. combination hydraulic-electric or pneumatic-electric control systems
   c. passive homing guidance and all-pneumatic type wing-control units
   d. separate guidance and control sections, each individually packaged
7. When checking a missile unit using a Go-No-Go Test Set, if the "No" result is obtained, panel lamps on the Test Set indicate
   a. which stage or stages contain malfunctions
   b. the secondary check points needed to isolate the trouble
   c. how far the circuit response is from being within tolerance
   d. the steps necessary to determine which missile unit is faulty
8. After receiving a "No" indication during a missile check using the Go-No-Go test equipment, the first thing to be done is to
   a. disassemble the test setup and troubleshoot the missile
   b. reject the missile component undergoing test
   c. prepare the missile unit for a systems maintenance check
   d. initiate another self check of the test set
9. The ready service magazine contains missiles which are ready for
   a. delivery to loading and arming crews except for minor adjustments and additions
   b. assembly and delivery to the flight deck when needed for operations
   c. checkout and adjustment using the Go-No-Go Test Set
   d. arming before being carried to the loading area
10. Before loading any missile on the launcher, the person in charge of the loading crew must
    a. perform an operational check on the missile
    b. arm the missile fuse and rocket motor circuits
    c. insure that cockpit controlling switches are correctly positioned
    d. have the aircraft spotted on the catapult
11. If a missile is dropped or severely jarred while being handled or loaded on the aircraft, it should be
    a. rejected and struck below for disassembly and inspection
    b. loaded and the pilot notified of the occurrence
    c. disposed of "over the side" with exception of the wings
    d. placed back in the ready service magazine for a "cooling off" period

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12. Safety in arming of the missile is achieved by cooperation of the
    a. crew members and flight deck officer using sound powered phones
    b. plane captain and the crew loading the missile
    c. pilot and crew members through use of distinct and well-understood hand signals
    d. flight deck officer and pilot using the ship's communication channels

13. Components test sets are employed in checking
    a. complete missile response to simulated flight conditions
    b. replaceable plug-in components and other smaller items
    c. the fuze and other ordnance components for moisture
    d. for proper operation and alinement of the missile on the launcher

14. In most Navy missile systems, the systems test equipment is, in effect, used to
    a. isolate individual malfunctioning parts (resistors, coils, etc.)
    b. simulate flight conditions and check complete missile response
    c. replace standard test equipment such as oscilloscopes, VTVM's, etc.
    d. check the guidance radar for proper frequency and signal strength

15. Secondary check points are used primarily
    a. to aid in the isolation of a malfunctioning electronic part
    b. in the systems checkout of the missile
    c. to aid in locating the physical location of a component
    d. during assembly of major components into a complete missile

16. High-resistance shorts between conductors in a cable or in the insulation of a conductor may be detected by use of a/an
    a. ohmmeter
    b. ammeter
    c. VTVM
    d. megger

17. The instrument that is used for displaying graphs of rapidly changing voltage and current as well as giving information concerning frequencies, phase differences, and voltage amplitudes is the
    a. cathode-ray oscilloscope
    b. spectrum analyzer
    c. vacuum-tube voltmeter
    d. absorption type wavemeter

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18. A heterodyne frequency meter can be used as a wavemeter for measuring output frequencies of transmitters and also to
    a. determine the frequency range of sweeping F-M transmitter
    b. find the center frequency of a modulated carrier signal
    c. determine the amount of r-f energy being radiated
    d. supply accurate test signals of moderate amplitude

19. The FR–38A/U frequency meter, when used to measure a signal frequency,
    a. requires that the incoming signal be periodic in arrival
    b. must have a minimum input signal of one volt
    c. can count random output signals
    d. is primarily used in determining the center frequency of an F-M signal

20. The type of wavemeter widely used for the measurement of microwave frequencies is the
    a. transmission type
    b. reaction type
    c. heterodyne type
    d. radiation type

21. Spectrum analyzers are electronic test instruments used to
    a. present a visual indication of changing voltages and currents
    b. provide a visual indication of the frequency components present in modulated waves
    c. determine the amount of r-f energy radiated from a transmitter
    d. ascertain the frequency of an unmodulated carrier signal

22. Crystal rectifiers are packaged in metal containers to guard against damage caused by
    a. radiation from strong r-f signals
    b. excessive heat conditions
    c. acid from hands of handling personnel
    d. excessive pressures applied to them

23. In determining whether or not a crystal rectifier is acceptable, a comparison is made of the
    a. front resistance to crystal current
    b. back resistance to front resistance
    c. crystal current to test set current
    d. reference voltage and crystal voltage

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24. R-f power may be measured by means of an instrument containing a heat-sensitive element called a

   a. galvanometer
   b. dynamometer
   c. bolometer
   d. clinometer

25. Bead thermistors are commonly used

   a. to compensate for ambient temperature changes
   b. as power-sensitive elements in microwave measurements
   c. in compensating for drift errors in bridge circuits
   d. because they are relatively unaffected by current flow through them

26. The clinometer is an instrument used for

   a. measuring the clearances in control valves and actuators
   b. determining the thickness and width of a control surface
   c. alining missile wings and fins along the same axis
   d. measuring the angle made by a surface and a reference plane

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CHAPTER 13

MAINTENANCE AND REPAIR PROCEDURES

The procedures of missile handling and testing and the use of the test equipment described in the preceding chapter represent only a part of the technical duties of the missileman. Of equal importance are those duties included in the fields of maintenance and repair, the basic procedures of which provide the subject matter of the present chapter.

It is useful to distinguish between maintenance and repair, since these terms have definite meanings when used in naval technical publications, instructions, and notices. The term REPAIR refers to the actions of correcting damage incurred through long use, accident, or other causes.

MAINTENANCE is a term representing a very inclusive field, which has several subdivisions. The broadest of these is PREVENTIVE maintenance, or all actions made in systematic steps to reduce or eliminate failures or to prolong the life of equipment. In addition, three other classes of maintenance are recognized: OPERATIONAL; TECHNICAL; and TENDER/YARD, or depot, maintenance.

Operational maintenance consists of inspection, cleaning, servicing, lubrication, adjustment, and preservation of components and assemblies. It also includes the replacement of minor parts when this does not require special skills or necessitate alinement or adjustment as a result of the replacement.

Technical maintenance is limited normally to replacement of unserviceable parts, subassemblies, or assemblies, followed by alinement, testing, and adjustment of the equipment.

Tender/yard, or depot, maintenance is that which involves

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major overhaul or complete rebuilding of the principal subassemblies, assemblies, or the total equipment.

In the work in any of the types of maintenance and repair listed above, the missileman employs knowledge and skills of two fundamental kinds. He must have specific information which pertains only to the particular equipment he may be called upon to repair or maintain. In addition, he must possess and use certain general skills and knowledge which apply to many kinds of equipment and to many types of work assignments.

The specific information required consists of special procedures and processes and detailed, step-by-step directions approved by proper authority and recommended for a particular piece of equipment. This information is supplied by classified publications prepared for the sole use of duly authorized personnel.

The general maintenance skills and procedures are based on knowledge which is not contained in missile publications, but which is presupposed and required as a necessary part of the missileman's professional capabilities.

The latter kind of information forms the basic content of the present chapter. The first section is a brief discussion of the types of publications most useful in missile maintenance and repair. Subsequent sections are devoted to basic procedures in electronic and electrical maintenance and repair; to the essential operations in the maintenance of hydraulic and pneumatic systems; and to the logs, records, and reports required in the work of the missileman.

MAINTENANCE PUBLICATIONS

The primary technical duties of the GF include the maintenance of special test equipment as well as the assembly, adjustment, maintenance, and testing of guided missile systems and components. In the performance of these duties, he is assisted and guided by several types of publications. Among the more important of these are the handbooks written for each missile system and for each series of test equipment. These handbooks provide the required informa-

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tion concerning the details of the equipment to which they apply and supply the approved and recommended procedures for repair and maintenance.

Missile Handbooks

For each system, one or more handbooks or manuals are prepared under the direction of the bureau concerned with the development of the system. Handbooks produced by different bureaus may differ somewhat as to arrangement; but, in general, the contents of most are substantially similar. As an example, consider the publication entitled *Handbook of Assembly, Checkout, and Service Instructions for Navy Model AAM-N-2 Guided Missiles*, which is published under the authority of the Chief of the Bureau of Aeronautics. This volume contains the following major divisions:

SECTION I, GENERAL INFORMATION.—This section supplies information as to the purpose of the handbook; the purpose for which the missile is used; and the purposes of the various kinds of equipment supplied as a part of the missile system. It also lists the equipment required but not supplied; and contains a subsection giving a complete physical description of the missile.

SECTION II, THEORY OF OPERATION.—In this section, the theory of operation of the missile is given in general terms.

SECTION III, TOOLS AND TEST EQUIPMENT.—This section lists and describes the tools and test equipment required to assemble, checkout, and test the missile.

SECTION IV, PREPARATION OF THE MISSILE FOR USE.—This part of the handbook contains instructions for unpacking the components; the approved procedures to be employed in assembly; and detailed instructions for charging and for loading.

SECTION V, MISSILE CHECKOUT PROCEDURES.—Instructions are given in this section for checking the operation of the missile system by use of the missile test equipment. Adjustment and repair procedures are included where necessary; and both schematics and wiring diagrams of the overall system are provided.

SECTIONS VI THROUGH XIX, COMPONENT REPAIR.—

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These sections pertain to the various plug-in components. Each section contains the following types of information: (1) function of the component, (2) description, (3) theory of operation, (4) checkout procedure, (5) repair procedures, and (6) voltage and resistance data. Schematics and parts layout diagrams are included in each section.

In addition to handbooks of the type described above, the GF frequently has occasion to use publications of an entirely different sort. These are publications indexes, which are prepared to assist in procuring written materials of various kinds. The indexes of primary value for the missileman are those which list aeronautical and ordnance publications.

Naval Aeronautic Publications Index

The *Naval Aeronautic Publications Index*, NavAer 00–500, is a consolidated listing of all publications and forms which pertain to aeronautical activities. It is divided into the following three parts:

Part I. A numerical listing of all effective BuAer publications.

Part II. A table of publications relating to aircraft and equipment.

Part III. A cross reference listing publications applicable to each aircraft and its component equipment.

Complete instructions for ordering all the publications listed are included in the *Index*. It is issued annually and revisions are published at regular intervals during the year.

Index of Ordnance Publications

The *Index of Ordnance Publications*, OP 0 is a consolidated listing of all publications and forms which pertain to ordnance activities. It is divided into two parts:

Part I. A numerical listing of all BuOrd publications.

Part II. A listing of all available ordnance publications arranged by subject matter.

Complete information for ordering all the publications listed is included in the *Index*.

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ELECTRICAL AND ELECTRONIC MAINTENANCE AND REPAIR

Normally, the greater part of the missileman's maintenance and repair work is done with electrical and electronic equipment. Among the basic procedures required are those of (1) troubleshooting, or locating defective stages and parts; (2) making connections, both soldered and solderless, in electrical wiring and other types of conductors; (3) replacing parts such as vacuum tubes, resistors, and capacitors; and (4) routine maintenance of switches, relays, and rotating electrical equipment such as generators and dynamotors. These various topics form the content of the present section.

Signal Tracing Methods in Troubleshooting

The approved procedure for locating trouble in any particular electronic or electrical unit is given in the corresponding handbook and must be followed in detail. A method employed in many cases is signal tracing. This general procedure is very useful for servicing equipment which contains no built-in meters and can be effectively applied to many kinds of missile components.

In signal tracing, a voltage similar to the normal incoming signal of the circuit in question is taken from a test instrument, such as a signal generator, and applied to the input terminals. The signals resulting are then checked at various points in the circuit, using test instruments such as vacuum-tube voltmeters, oscilloscopes, or any high-impedance instruments which may be suitable. (In most cases, the instrument is connected in parallel with some element of the circuit, and hence should present high impedance at the input to minimize any changes it introduces in the circuit operation.) The signals appearing at the check points are then compared with known, standard signals normal for these points, so that the stage or section failing to produce the expected signal can be determined, thereby localizing the fault to a particular section of the equipment.

By signal tracing methods, the gain or loss of amplifiers can be measured; and the points of origin of distortion and

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hum, noise, oscillation, or any other abnormal effect can be detected.

Many missile handbooks prescribe a method of troubleshooting based on the observation of waveforms with a cathode-ray oscilloscope for locating defective stages and parts in missile receivers or amplifiers. As an example, consider the following description of the procedure given by the handbook of a beam-rider missile for troubleshooting a plug-in component consisting of several stages of video amplifiers.

The purpose of the video component is to increase the voltage of the missile guidance pulses to usable levels; and in the process, each stage contributes some desirable characteristic in any pulse it amplifies. The special component test equipment of the missile system is used to supply power for the unit under test and also to supply the input test signals.

The video component is attached to the test set by means of the cables provided and power is applied in accordance with the instructions in the publication. The input pulses are observed with a properly calibrated oscilloscope and the pulse amplitude is adjusted to the exact value prescribed. Calibration of the oscilloscope is done in accordance with the detailed instructions of the handbook so that the instrument indicates the voltage, or amplitude, of the signals and also the pulse width and pulse spacing in microseconds.

The output pulses of each of the video amplifiers are then observed by attaching the oscilloscope input to the test points specified. The characteristics and waveforms normal for each point are given in the handbook, and the observed signals are compared with those required. If at any point, the amplitude, pulse width, pulse spacing, or the waveform is incorrect, the parts of the corresponding stage are tested further to determine the cause of the malfunction. These tests may consist of voltage measurements, resistance measurements, or both, to locate the exact part at fault.

A fundamental skill involved in the repair of circuit defects isolated by signal tracing and other troubleshooting methods is that of making electrical connections in conductors. The discussion turns next to this subject area to consider solder-

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ing techniques and the types and uses of solderless connectors.

Soldering

Soldering is the basic method of making low-resistance connections in electronic and electrical circuits. And although considerable progress has been made in the development of solderless connectors, millions of solder joints are produced each year. Properly soldered connections have a high degree of reliability; but as in any product of mechanical processes, the quality may vary widely; and enough poor soldering exists to constitute a major cause of equipment failure. The main requirements for good soldering are proper materials and correct techniques.

MATERIALS.—Solder is a metallic alloy which when melted can be used to join the surfaces of metals by fusing with them. Soft solders are those which melt at low temperatures. Hard solders are alloys with higher melting points—usually red heats.

Soft solder, an alloy of tin and lead, is used almost universally for soldering in electronic circuits. It is specified by the percentage of each constituent, with that of tin appearing first. For example, the solder most frequently used with naval electronic equipment is 60–40 solder, which contains 60 percent tin and 40 percent lead.

An important consideration when using solder is the melting point with respect to that of the wires soldered. The melting point of the soft solder mentioned above is 361° F., so that it can be used only with materials which melt at temperature above this value. Also, it is necessary that joints fused with soft solder are not subjected to temperatures in excess of this figure in the normal operation of the circuits containing them.

A hard solder is required for connections made in equipment where temperatures are high. In its usual form, hard solder is a silver alloy with a melting point of approximately 1,175° F.

The effectiveness of the soldering process is aided by the use of a suitable FLUX, which may be defined as any material

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used on the surfaces to be fused to free them from oxides. The only flux fully acceptable for electronic work is rosin. A core of rosin is contained in most soft solders. The solder is formed by extrusion, being made as a hollow wire with the rosin flux contained as the core. The flux generally used with hard solder is borax mixed with water to a pastelike consistency.

Soldering irons.—Wires are soldered to contacts or terminals by use of soldering irons, torches, or resistance heating methods. The tool most frequently used in electronic soldering is the electric soldering iron, of which there are many types and styles. Electric irons are rated according to the quantity of heat dissipated by the heating element, with this value ranging from about 25 watts in small pencil-type irons to several hundred watts in the heavy-duty varieties. Connections requiring hard solder are made by the use of torches or by resistance heating.

The selection of an iron of the proper size or heat capacity for a particular job is of considerable importance. One with excessive wattage dissipation is likely to burn the insulation of the wire or to melt the insert of a connector. On the other hand, too little heat capacity may result in a "cold" solder joint in which the solder does not alloy with the wire and the contact, thereby providing a poor electrical connection. Table 13–1 gives the approximate ratings of irons suitable for soldering wires of the sizes often encountered in electrical and electronic work.

Table 13–1.—Wattage ratings of soldering for various wire sizes.

Wire size (AN gage)	Soldering iron (heat capacity)
20–16	65 watts.
14 and 12	100 watts.
10 and 8	200 watts.

When choosing an iron for a particular job, one should consider the shape of the tip to be sure that it will provide good heat transfer to the work surface. A fairly large contact

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area is desirable since it aids in producing a good connection quickly.

If the tip is made of copper, the contact areas can be reshaped and smoothed if they are pitted, by using a small flat file. Some soldering tips are coated with a layer of pure iron to resist oxidation; and these should never be ground or filed.

SOLDERING TECHNIQUES.—After selecting an iron of the proper size and shape, the preliminary step in soldering is preparing the wire and the tip. Consider, as an example, the preparation of a copper wire before soldering it to a connector.

Enough insulation is stripped from the end of the wire to allow about 1/32-inch clearance between the remaining insulation and the connector cup when the wire is placed firmly into the connector. The soldering tip is then tinned by coating it with a thin layer of solder. The tip should be clean and bright; and while the iron is heating, rosin-core solder (60–40) is rubbed on the surface of the tip. It is considered good practice to tin only one surface of the working area so that parts or wires adjacent to those being soldered are not coated by accident. When applying solder to the heating tip, one should hold the iron so that the tinned surface is turned away from his face.

The wire is tinned by holding the iron tip and the solder together on the wire until the solder begins to flow. The iron is then moved to the opposite side of the wire; and approximately one-half of the exposed length is tinned or covered. The tinning operation, illustrated in figure 13–1, is complete when the sides and ends of the wire strands are fused together with a coat of solder, and the wire is then ready to be joined to the connector.

In appearance, a well-bonded solder connection is clean and bright, and it approximately outlines the wire as shown in figure 13–2. If the surfaces of the work are perfectly clean and well tinned, the molten solder flows evenly and adheres firmly without piling up in thick layers. The insulation near a well-made joint is free of nicks and is not charred or covered with rosin flux. The end of the insulation should

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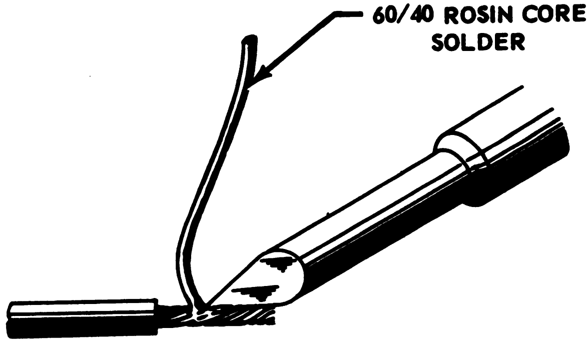

Figure 13–1.—Soldering iron tinning.

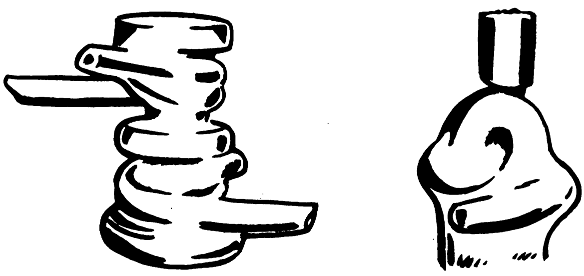

Figure 13–2.—Properly made solder connections.

be near but not in the opening of any terminal lug or connector to which the lead is soldered; and the finished joint should be perfectly free from enamel particles or any other impurities which are sometimes trapped in molten solder.

A thin film of rosin may remain on the metal surface of the completed joint; and this need not be removed unless the connection is in a high-frequency circuit or unless it is anticipated that the equipment will be fungus proofed. If it is necessary to remove residues of rosin, this can be done by applying Stoddard's Solvent (available through naval supply channels) with a stiff brush followed by drying using compressed air.

All persons skilled in soldering know that good connections result only from clean parts, careful soldering technique, and proper preparation of the work. The following general

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rules apply to most of the soldering in electronic or electrical maintenance:

1. Extra amounts of heat and special fluxes can never serve as substitutes for clean soldering surfaces.

2. Use only rosin as a flux when soldering electrical conductors. Never use an acid-core solder.

3. Joints with thick layers of solder are likely to be porous or cold connections. Use only enough solder to make a clean, neat joint.

4. Solder has very little mechanical strength and should never be depended upon to keep connections from pulling apart. Use a cable clamp, or wrap the lead about a terminal to give the required mechanical strength.

5. Care should be taken to avoid moving the connection before the solder has hardened.

6. Safe and acceptable connections cannot result if the wires are not properly tinned.

SOLDERING MINIATURE PARTS.—The GF must exercise considerable care when soldering leads in missile components that contain miniature tubes and parts. Many small resistors, capacitors, connecting wires, and other electronic parts are placed in close proximity in most subassemblies; and while soldering one part, it is very easy to damage those parts nearby. In the preparation of the work for soldering, it is necessary to use tools of correct size. Small jeweler's pliers and side cutters are available through supply channels and should be used when working on miniature subassemblies. Large hand tools present a hazard and their use should be avoided.

Soldering irons should have wattage ratings high enough to provide enough heat for making good connections but not so large as to cause overheating and damage to adjacent parts. A pencil-type iron with a tip small enough for work in confined spaces is generally preferable for work with missile components; though many connections such as those made to ground terminals must be made with an iron of larger capacity.

Overheating and damage to miniature resistors and capacitors can be avoided only by restricting the conduction of

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heat to the metal leads and preventing it from flowing into the body or the part. This can be done by means of a thermal shunt, which operates in much the same way as a shunt on a sensitive current meter used in a circuit carrying heavy current. A simple and frequently used method of providing a thermal shunt is to grip the lead between the body of the miniature part and the terminal with a pair of long-nose pliers. The metal jaws form a low-resistance heat path which bypasses the flow of heat around the part. This method has certain disadvantages, since it is awkward to solder with one hand; and also, the operator may have a tendency to release the pliers upon removing the iron and permit an unrestricted flow of heat into the part from the still molten joint. Also, steel pliers do not possess the degree of heat conductivity required for effective shunting or full protection against damage.

A much more effective heat shunt is provided by a clamp made of copper and which can be left attached to the lead until the joint cools. A good clamp shunt can be made easily by sweating small copper bars into the jaws of an ordinary crocodile clip. A shunt of this type is shown in figure 13–3.

A clamp-type heat shunt should be used when soldering the leads of small capacitors, resistors, choke coils mounted on polystyrene forms, and wire-ended crystals. The clamp should be placed near the body of the part and as far as

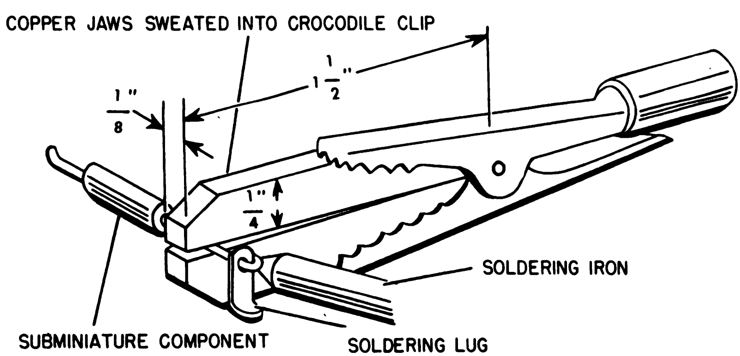

Figure 13–3.—Details of clamp-type heat shunt.

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possible from the joint being soldered. Care should be taken to avoid a low-resistance heat path between the hot soldered connection and the part by allowing the clamp to contact both.

The effectiveness of the heat shunt can be maintained by keeping the jaws flat and free from dirt, grease, or soldering flux so that a good contact between the clamp and the metal lead is insured. The face of the clamp turned toward the iron should be kept bright to minimize heat transfer by radiation, while the rest of the clamp body should be dull black in color.

Solderless Terminations and Splices

Special tools and methods for making cable connections without the use of solder are employed extensively in the aircraft industry and are rapidly coming into use in the fabrication of electrical cables for guided missile systems. The principal kinds of solderless connections are those made for splicing cables and for attaching terminal lugs to cable ends. Solderless splices are often used to join lengths of heavy electrical conductors to form permanent, continuous cable runs. Solderless terminal lugs provide a rapid and efficient means of equipping cables for attachment to terminal blocks, busbars, and to electrical machines.

Solderless terminal lugs and splices are made either of copper or of aluminum. They are designed for several kinds of applications and are of the PREINSULATED or of the UNINSULATED types. Terminal lugs may be of the straight, flag, or right-angle designs, the first two of which are illustrated in figure 13–4. Examples of copper splicing connectors are also shown in the figure.

Terminal lugs and solderless splices are crimped to the conductors either by means of hand tools or by power tools. (The process is also called "staking" and "swaging.") Hand crimping tools, such as the one shown in figure 13–5, are of the type more frequently used in the work of the GF. These tools crimp the barrel of the lug to the conductor; and with preinsulated connectors, they also simultaneously crimp the the insulation grip to the insulation of the wire.

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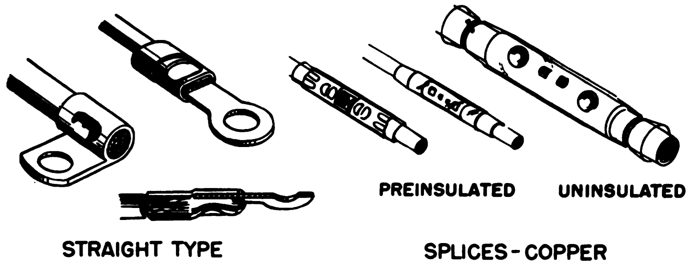

Figure 13–4.—Solderless terminal lugs and splices.

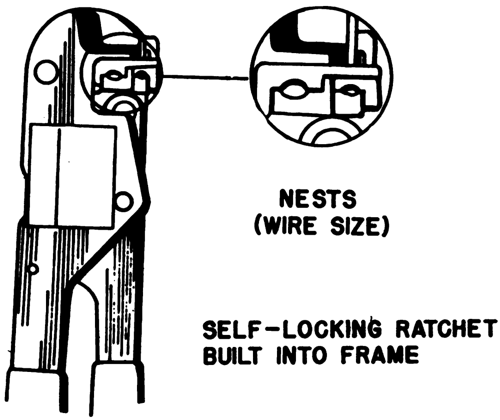

Figure 13–5.—Standard crimping tool, MS 25037.

The preinsulated terminal lug is widely used for terminating smaller sizes of copper conductors. The construction of this type of terminal is shown in figure 13–6 by a cutaway drawing. The insulation forms a part of the lug and extends beyond the barrel, so that upon connection, it covers a portion of the wire insulation and makes the use of an insulation sleeve unnecessary. This type of lug also contains a metal reinforcing sleeve beneath the insulation called an INSULATION GRIP, which provides extra gripping strength and holds the wire insulation firmly.

Preinsulated lugs of the type shown (fig. 13–6) are used as terminations for copper conductors of sizes 22 through 10 (AWG). The lugs are color coded to indicate the wire

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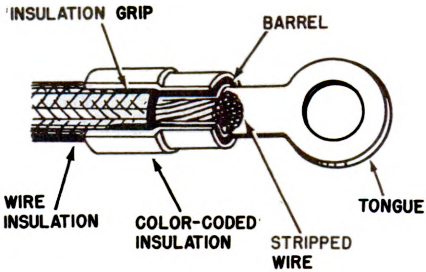

Figure 13–6.—Preinsulated terminal lug: cutaway drawing.

sizes for which they are suitable. Those having red insulation are used to terminate wire sizes 22 through 18; lugs with blue insulation are used for wire sizes 16 and 14; and lugs with yellow insulation are used with wire sizes 12 and 10. The procedure by which the terminal lug is attached can be understood by considering the directions for crimping provided with the MS 25037 Crimping Tool illustrated in figure 13–5.

CRIMPING PROCEDURE FOR PREINSULATED TERMINALS.—Hand crimp the preinsulated copper lugs to wires of the 22–10 size range by the following steps:

1. Strip the wire insulation: sizes 22 through 14 should be stripped $\frac{3}{16}$ inch from the end; sizes 12 and 10 are stripped $\frac{9}{32}$ inch from the end.

2. Check the tool for correct adjustment. (Tool MS 25037 is checked when fully closed. A size 36 drill rod should not be able to enter the smaller nest. If the tool is out of adjustment, it should be returned for repair.)

3. Insert the terminal lug tongue first into the crimping jaws until the barrel of the lug butts flush against the tool stop.

4. Squeeze the handles of the tool slowly until the jaws hold the lug firmly but without denting it.

5. Insert the stripped wire into the barrel of the lug until the wire insulation butts flush against the end of the barrel. Squeeze the tool handle until the rachet releases. Remove the completed assembly and examine for proper crimp.

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Replacement of Subminiature Tubes

The replacement of subminiature tubes in missile electronic components is a typical job in the work of the GF. This job involves several kinds of specialized knowledge and skills, among which are the proper method of identifying the tube leads, specialized soldering techniques, the use of parts layout diagrams, the interpretation of schematic wiring diagrams, and the submission of failure reports.

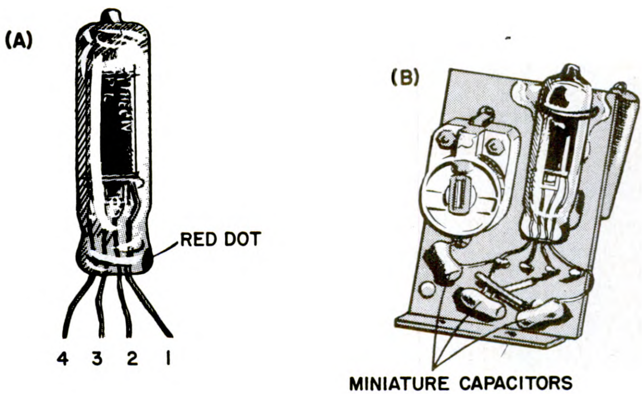

Figure 13–7.—(A) Subminiature tube; (B) component subassembly.

In (A) of figure 13–7, a subminiature tube is shown full size. The tube elements are not connected to rigid pins on the base as in a standard tube; but as shown in the drawing are brought out from the envelope in the form of flexible leads. This method of construction makes tube replacement more of a problem than in the case of the ordinary vacuum tube which is usually slipped into a socket-type mounting.

The method by which subminiature tubes are mounted is indicated in (B) of figure 13–7, which shows the tube placed in a metal spring-type clamp in a typical component subassembly.

Lead identification.—The leads of the subminiature tube are usually identified by means of a colored dot (often red) placed on one side of the tube base to serve as a reference mark. The lead nearest the dot is lead number one;

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the lead adjacent is number two; the next is number three, and so on. In some cases, a blank space is encountered which would normally be occupied by a lead. When this occurs, the space is counted as if a lead were present. Once each lead has been identified with a number, the tube element to which a given lead is attached can be found by consulting the schematic diagram of the circuit containing the tube.

REPLACEMENT.—When replacing a faulty subminiature tube in a missile circuit, the first step is to unsolder the leads of the bad tube from the terminals to which they are normally attached. A heat shunt is used when necessary to protect miniature parts connected to the same terminals as the tube leads. The tube is then removed from the tube clamp.

The new tube is inserted carefully in the clamp, orienting the red dot on the base to the same position as the one on the base of the tube which was removed. If the dot on the faulty tube is obliterated, or if its position is in doubt, the correct position of the new tube can be determined by referring to the appropriate parts layout diagram in the missile maintenance publication.

A complete missile component is composed of several subassemblies; and for each there is a parts layout diagram in the maintenance handbook. An example is given in figure 13–8, which illustrates the physical locations of four tubes, two resistors, and three capacitors, all of which are included in the subassembly shown. A diagram of this type gives information concerning the placement of the various parts and also data pertaining to the tube leads. In the drawing, the identifying dot on each tube is indicated and the solder terminals are shown as small circles, identified by number. Also, a subassembly number, E–2802–A in this example, is given which serves to identify the subassembly on the complete component wiring diagram and on the component schematic diagram.

After the position of the tube has been determined from the layout drawing, the component wiring diagram can be utilized to determine how the tube leads should be soldered.

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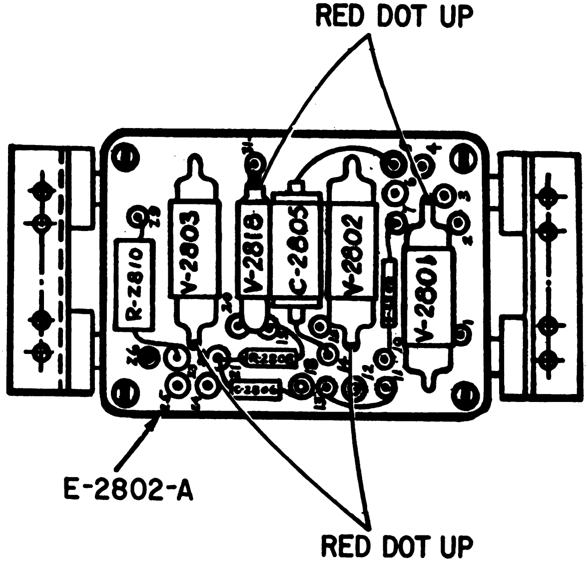

Figure 13–8.—Component subassembly parts layout diagram.

Unlike the parts layout, the wiring diagram does not show the physical placement of the parts, but indicates the electrical connections between various parts and subassemblies. An example is shown in figure 13–9, a wiring diagram of subassembly E–2802–A. In this diagram, the same parts appear that are included in the parts layout given above.

If, for example, V2801 is the tube to be replaced, it can be seen from the wiring diagram (fig. 13–9) that lead number 1 of the tube is to be connected to solder terminal number 7. Lead number 2 of the tube attaches to terminal number 6; lead number 3 to terminal number 4; lead number 4 to terminal number 5; leads 5 and 6 of the tube to terminal number 3; and lead number 7 is to be connected to terminal number 2.

Prior to making the connections, the tube leads, which are bare of insulation, must be covered with a suitable insulating material. This is generally done by the use of small-diameter insulating sleeving placed over each tube lead. After first determining the length of the leads, a piece of sleeving about ⅛ inch shorter than the lead is slipped over each wire and

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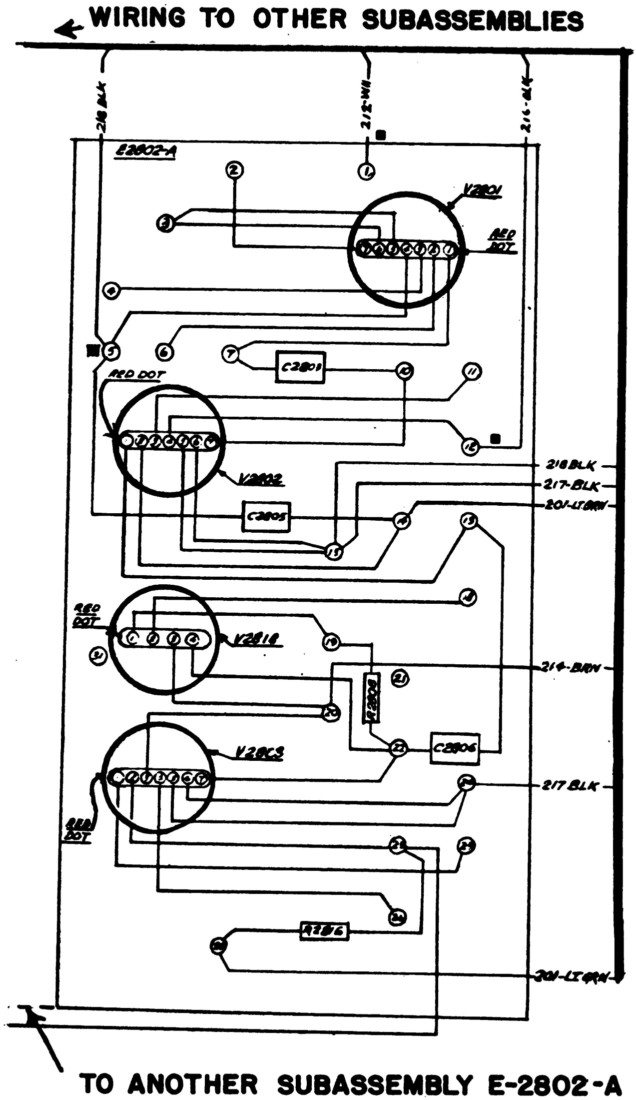

Figure 13-9.—Wiring diagram of subassembly E-2802-A.

seated firmly against the tube base. The solder connections can then be completed; and again extreme care should be exercised in making the connection, and a thermal shunt should be used again if necessary to protect nearby parts.

After replacement of the tube, it is necessary to fill out a failure report concerning it. The use of these reports and the procedures which apply to them are discussed in another part of this chapter.

Replacement of Parts

The *Illustrated Parts Breakdown* handbook issued with each missile, together with the maintenance publications pertaining to the missile test equipment provide detailed information on all the parts used in the units. In the Introduction of the *Illustrated Parts Breakdown* there is a section with the heading "Ordering Spare Parts" which reads as follows:

"Each Service using this *Illustrated Parts Breakdown* has established certain depots and service groups for the storage and issuance of required spare parts to its organizations. The regulations of each Service should be studied to determine the method and source for requisitioning spare parts. The information given in this breakdown regarding a contractor's or manufacturer's name, or the type, model, part, or drawing number of any part, is not to be interpreted as authorization to field agencies to attempt to purchase identical or comparable spare parts directly from the manufacturer, or from a wholesale or retail store, except under emergency conditions, as covered by existing regulations of the Service concerned. . . .

"If a JAN or AN standard part number is given to a part, only a JAN or AN standard part should be used as a replacement. If no JAN or AN standard part number is given, care should be taken in the choice of a replacement part other than that listed. . . . Parts not assigned a JAN or AN standard part number are special parts, probably chosen for a quality not available in standard parts, and the use of standard parts for replacement purposes may result in decreased equipment life or substandard performance."

In view of this requirement for exactness in parts replacement, it is necessary that the GF know the sources of information concerning the selection of parts and that he be familiar with standard designations. To illustrate the data

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given, consider the following example taken from the entries in the component parts list of the handbook quoted:

R–713: 5905–249–4239; RESISTOR, fixed, composition, 24,000 ohms $\pm 5\%$; 2 w.

$$\frac{\text{RC 42GF243J}}{\text{JAN Designation}}$$

The first entry, R–713, is the reference symbol which serves to identify the part with respect to the schematic diagram of the equipment.

The second group is the stock number of the part. This is followed by the part description, which supplies several items of information. These include the name and type of construction; the value of the part in the appropriate unit (such as ohms for resistors); the tolerance, or possible variation from the rated value; and in the case of resistors, the wattage rating. (In addition to the description, some handbooks also give the function of the part in the equipment.)

Associated with each part listed is an entry called the "Source Code." These symbols give information concerning (1) the source of supply, that is, whether the part is to be procured from supply sources, manufactured by the using activity, manufactured by an O and R Department, or obtained from salvage; (2) the level at which the item may be requisitioned and installed; and (3) the action to be taken as to salvage and repair of the part when defective.

Immediately below the description of the part is a symbol which is either a JAN designation, an AN number, or a manufacturer's part number. Parts which are frequently replaced, such as tubes, resistors, and capacitors, usually have JAN designations. The interpretations of these symbols as applied to fixed resistors and capacitors are given in the following section.

JAN Designations and Color Codes for Resistors and Capacitors

Type designations consisting of combinations of letters and numbers are used to identify JAN resistors and capacitors. These designations indicate, in accordance with a

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code, the important electrical and physical characteristics of the part to which they refer. Where limitations of space do not permit the type designation to be marked on the part, color coding is employed to indicate the electrical characteristics. The color markings consist of colored dots, colored bands, or combinations of bands and dots. A summary of the system of designating fixed resistors and fixed capacitors, including the various color codes is given below.

FIXED COMPOSITION RESISTORS.—The JAN designation for fixed composition resistors may be illustrated by means of the resistor mentioned in the preceding section. The designation is made up of five parts:

RC	42	GF	243	J
(a)	(b)	(c)	(d)	(e)

(a) COMPONENT. The first is the component designation, which consists of the letters RC. The letter R stands for "resistor" and the letter C indicates the subclass "composition."

(b) STYLE. The style is indicated by a two-digit number which refers to the power rating, physical shape, and size.

(c) CHARACTERISTICS. A two-letter group, GF in the example above, gives the characteristics of the resistor. The first letter denotes whether the element is insulated and also its moisture resistance. The second letter designates the resistance-temperature characteristics. (The interpretations of the symbols for style and characteristics can be found in JAN–R–11.)

(d) RESISTANCE VALUE. This part of the designation is a three-digit number indicating the resistance value in ohms. The first two digits are the first two figures of the resistance value, and the final digit gives the number of zeros which follow the first two figures. In the example, the value is 24,000 ohms since the (d) part of the designator is 243.

(e) RESISTANCE TOLERANCE. The final part of the designator is a single letter which corresponds to a percentage figure preceded by a "plus-or-minus" symbol. The percentage figure expresses the tolerance, or the amount by

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which the actual value may differ from the resistance value stated. The letters used and the corresponding percentage figures are given in the following list:

Letter	*Tolerance*
J	±5%
K	±10%
M	±20%

Resistor color codes.—Fixed composition resistors are marked by color coding to indicate the resistance value and the resistance tolerance. As shown in the sketches in figure 13–10, these values may be given either by the position and color of bands or by the body color, end color, and dot color.

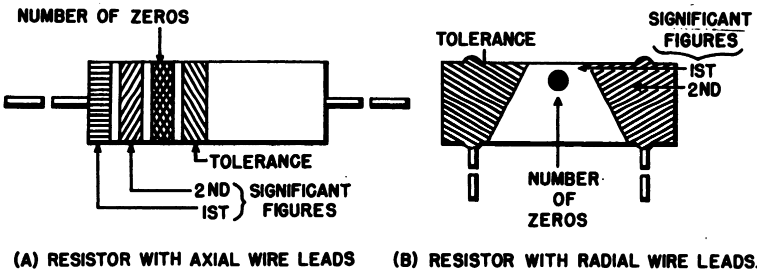

Figure 13–10.—Color code for fixed resistors.

The colors are associated with the values shown in table 13–2. Consider as an example an axial-lead resistor with bands colored red, orange, yellow, and gold, reading from left to right. The red band signifies a first digit of 2 for the resistance. The orange band shows the second digit to be 3. The yellow band signifying 4 means four zeros are to be added to the first two digits, giving a resistance of 230,000 ohms. The gold band is the tolerance indication and means ±5 percent.

As an example of the color code applied to a radial-lead resistor, suppose there is a body color of orange, an end color of blue, and a green dot, and an end color of silver. The interpretation is as follows:

The orange body signifies a first digit of 3.

The blue end signifies a second digit of 6.

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Table 13-2.—Resistor color codes

Body first band		End second band		Dot third band		End end band	
Color	*Value*	*Color*	*Value*	*Color*	*Value*	*Color*	*Tolerance*
Black	0	Black	0	Gold	0. 1	Gold	(J) ± 5%.
Brown	1	Brown	1	Silver	0. 01	Silver	(K) ± 10%.
Red	2	Red	2	Black	None	None	(M) ± 20%.
Orange	3	Orange	3	Brown	0		
Yellow	4	Yellow	4	Red	00		
Green	5	Green	5	Orange	000		
Blue	6	Blue	6	Yellow	0000		
Violet	7	Violet	7	Green	00000		
Gray	8	Gray	8	Blue	000000		
White	9	White	9	Violet	0000000		
				Gray	00000000		
				White	000000000		

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The green dot means 5 zeros are to be added.

The silver end indicates a tolerance of ±10 percent.

The resistance value is then 3,600,000 ohms, ±10 percent.

FIXED MICA CAPACITORS.—The JAN designation system for fixed mica capacitors may be illustrated by the following example:

CM	20	A	050	M
(a)	(b)	(c)	(d)	(e)

(a) COMPONENT. All fixed mica-dielectric capacitors represented by the JAN type of designation are represented by the letter CM as the first two symbols of the designator.

(b) CASE. The case designation is a two-digit number which is used to identify the type of case, both in size and shape. (The interpretation of these symbols is given in JAN–C–5.)

(c) CHARACTERISTICS. The characteristics symbol is a single letter which refers to the temperature coefficient and to the maximum capacitance drift.

(d) CAPACITANCE VALUE. The value of the capacitor in micromicrofarads is indicated by a three-digit number. The first two digits are the first digits of the capacitance value. The final digit specifies the number of zeros which follow the first two digits.

(e) CAPACITANCE TOLERANCE. The tolerance, expressed as a percentage figure preceded by a plus-or-minus sign is designated by a letter from the following list:

Designation letter	*Tolerance*
G	±2%
J	±5%
K	±10%
M	±20%

The color code for JAN mica capacitors is shown in figure 13–11.

The colors are interpreted as in table 13–3.

The letters in the column headed "Characteristics" in table 13–3 have the following meanings:

A Ordinary mica bypass capacitor.

B Similar to A but with a low-loss case.

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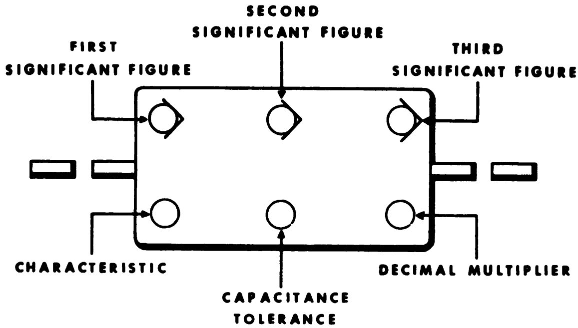

Figure 13–11.—Color code for fixed mica capacitors.

C Bypass or silver mica (temperature coefficient of ± 200 parts per million per degree C.).

D Silver mica (± 100 parts per million per degree C.).

E Silver mica (0 to 100 parts per million per degree C.).

F Silver mica (0 to 50 parts per million per degree C.).

G Silver mica (0 to -50 parts per million per degree C.).

The expression "± 200 parts per million per degree C." means that the capacitance may increase or decrease 200 micromicrofarads for each million micromicrofarads in the

Table 13–3.—Color code for mica capacitors

Capacitance			Tolerance	Characteristics
Color	Significant figure	Decimal multiplier		
Black	0	1	20% (M)	A
Brown	1	10	1%	B
Red	2	100	2% (G)	C
Orange	3	1, 000	3%	D
Yellow	4	10, 000	4%	E
Green	5	100, 000	5%	F
Blue	6	1, 000, 000	6%	G
Violet	7	10, 000, 000	7%	
Gray	8	100, 000, 000	8%	
White	9	1, 000, 000, 000	9%	
Gold		0. 1	5% (J)	
Silver		0. 01	10% (K)	

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Table 13-4.—Table of tolerances for ceramic-dielectric capacitors

Letter Symbol	Percent	mmfd.
C	----------	0. 25
D	----------	0. 5
F	1	1. 0
G	2	2. 0
J	5	----------
K	10	----------
M	20	----------

rated value when the temperature changes by one degree centigrade.

FIXED CERAMIC-DIELECTRIC CAPACITORS.—The JAN designations of fixed ceramic-dielectric capacitors indicate the component, the style, the characteristics, the capacitance value, and the capacitance tolerance. The type designation is formed as in the following manner:

CC	25	SL	100	G
(a)	(b)	(c)	(d)	(e)

(a) COMPONENT. Fixed ceramic capacitors are identified by the symbol, CC. The first letter indicates a capacitor, and the second signifies those capacitors with ceramic dielectrics.

(b) STYLE. The style designation is a two-digit number which identifies the particular shape and size of the capacitor.

(c) CHARACTERISTICS. The characteristic designation is a two-letter symbol in which the first letter specifies the temperature coefficient of capacitance, and the second letter indicates the tolerance of the temperature coefficient.

(d) CAPACITANCE VALUE. The capacitance of the capacitor in micromicrofarads is indicated by a three-digit number. The first two digits are the first two digits of the value expressed in the unit mentioned. The final digit specifies the number of zeros which follow the first two digits. When

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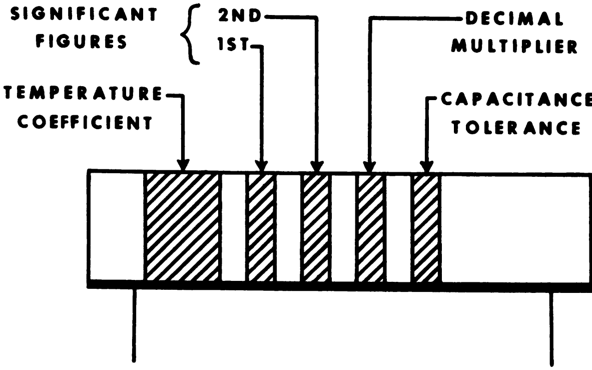

Figure 13–12.—Color code for ceramic capacitors.

more than two significant figures are required, additional digits may be used, but the last digit always indicates the number of zeros.

(e) CAPACITANCE TOLERANCE. The capacitance tolerance expressed as a "plus-or-minus" quantity is designated by a letter as shown in table 13–4. Where the indicated value of capacitance is greater than 10 micromicrofarads, the tolerance is expressed in percent. When the value is 10

Table 13–5.—Color code for ceramic capacitors

Color	Significant figure	Multiplier	Tolerance of capacitance: Capacitors of value greater than 10 mmfd. in percent	Tolerance of capacitance: Capacitors of 10 mmfd. or less in mmfd.	Temperature coefficient parts per million per degree, centigrade
Black	0	1	20 (M)	2.0 (G)	0
Brown	1	10	1 (F)		−30
Red	2	100	2 (G)		−80
Orange	3	1, 000			−150
Yellow	4	10, 000			−220
Green	5	100, 000	5 (J)	0.5 (D)	−330
Blue	6	1, 000, 000			−470
Violet	7	10, 000, 000			−750
Gray	8	0. 01		0.25 (C)	+30
White	9	0. 1	10 (K)	1.0 (F)	+550

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micromicrofarads or less, the tolerance is expressed in micromicrofarads.

The color code for ceramic capacitors is shown in figure 13–12.

The color code applied to the color bands shown in figure 13–12 is given in table 13–5.

The discussion in this section on the JAN system of designation can be supplemented with additional information contained in *Basic Electronics*, NavPers 10087, Appendix II, which contains tables and diagrams pertaining to the RMA system of color coding for resistors, capacitors, and transformers.

Maintenance of Commutators and Sliprings

The commutators and sliprings of rotating power equipment are inspected and cleaned at regular intervals as specified in the *Handbook of Service Instructions* accompanying the equipment.

The motor, dynamotor, or generator is removed in accordance with the instructions. Dust and dirt are cleaned from the machine and from the end covers either with a soft brush or by the use of dry, compressed air.

The electrical brushes are then loosened and carefully removed and inspected. The location and position from which each is taken should be noted so that the brush can be replaced in the correct position upon reassembly.

If the brushes bind in the brush holders, they may be wiped with a clean cloth; and if this does not suffice, they should be thinned down with No. 0000 sandpaper. Care should be taken to avoid letting the sandpaper touch the contact surfaces of the brushes. The contact edges must not be rounded or chipped, and any loose abrasive or carbon dust should be removed carefully. If the brushes are cracked, damaged, or worn excessively, they must be replaced. When new brushes are installed, the procedure should be in accordance with the instructions for brush seating provided with the specific equipment.

After inspection of the brushes, the commutator is checked for excessive wear, dirt, or any visible defect. If the surfaces

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are dirty, they should be cleaned with a lint-free cloth moistened with a suitable cleaning solvent. After cleaning, the surfaces must be carefully wiped dry. Care should be taken to avoid fingermarking of the commutator surfaces after cleaning.

A highly polished commutator surface is desirable; although if the surface is darkened, this does not necessarily mean that it is burned. Slight pitting of the commutator can be removed by the use of commutator sticks of pumice grade, followed by polishing with canvas cloth.

When commutators become badly worn or scored, they must be refinished. This operation should be done only by properly qualified personnel and only at a properly equipped repair station.

The sliprings of a-c machines must be inspected periodically for smoothness of the surfaces, proper diameter of the rings, and correct alinement of the rings on the shaft.

In routine maintenance of sliprings, cleaning and polishing is accomplished by using No. 0000 sandpaper or some finer grade. Emery cloth or coarse sandpaper should never be used. After cleaning with sandpaper of the grades suitable, any sand particles which may have collected on the rotor should be blown away with dry, compressed air.

Antifriction Bearings

Antifriction bearings may be either of the ball or the roller types, both of which are widely used in rotating electrical equipment. Many modern electrical machines are equipped with SEALED bearing assemblies. The maintenance of these bearings is very easy, since they are prelubricated and require almost no attention during the normal life of the machine in which they are installed.

As a guide to proper maintenance of ball or roller bearings in rotary equipment, the detailed recommendations of the manufacturer as given in the *Handbook of Service Instructions* should always be followed. As an example of a general maintenance procedure, consider the following directions, which are taken from the manufacturer's instructions pertaining to a small generator containing standard ball bearings.

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The bearings used in this generator normally are replaced with new bearings whenever abnormal conditions occur. However, in the event that replacements are not available, the bearings may be cleaned and relubricated as follows:

1. Wipe the outside of the bearings clean, using a clean cloth.

2. Wash the bearing thoroughly in cleaning solution (Specification PS–661).

3. Blow with compressed air until the assembly is dry. Care should be taken not to rotate the bearings while washing or drying.

4. Relubricate by packing the bearing full with General Purpose Lubricating Oil (Military Symbol 2190).

5. With a clean wooden stick, dig out all grease that can be removed from between the balls on both sides of the bearing assembly. This will leave the bearing about 25 percent full of lubricant, which is the maximum that should be used.

When dismantling a machine, the bearings should be removed carefully, wiped clean, and wrapped in clean oil paper until needed during reassembly of the machine.

In the inspection of ball bearings, the assembly is slowly rotated. Bearings showing pronounced stickiness or bumpy operation should be replaced. During inspection of bearing assemblies, check for the presence of cracks, pitted surfaces, and any physical damage present in the bearing elements.

Relay and Switch Care

Relays seldom require servicing unless a short circuit has caused the contacts to become burned or pitted, or unless damage has resulted from rough handling or improper treatment. When cleaning or adjusting a relay, it should be handled as if it were an expensive watch or a delicate meter.

Relays can be ruined by the use of sandpaper or emery cloth for cleaning the contacts. A BURNISHING TOOL should be used for this purpose. Two types of burnishing tools are stocked at naval supply activities; and either type can be obtained through regular supply channels. The appearance and use of one kind of burnishing tool are shown in (A) of

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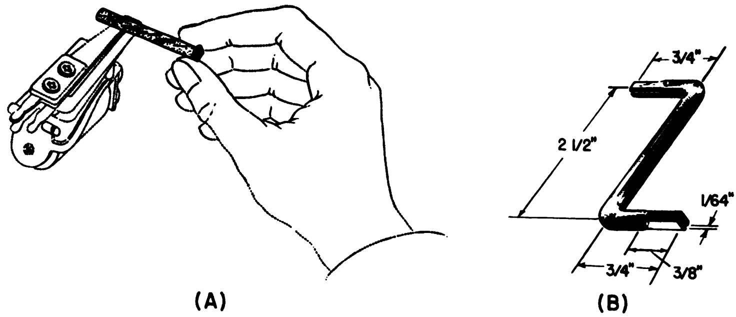

Figure 13–13.—(A) Relay burnishing tool; (B) relay point bender.

figure 13–13. The surfaces of the tool that are used to clean the relay contacts should not be touched by the fingers prior to use; and after use, the burnisher should be cleaned with alcohol.

When relays contain bent contacts, no attempt should be made to straighten them with long-nose pliers. Such an attempt often causes further damage with the result that the entire relay must be replaced. Bent contacts can be straightened effectively by using a CONTACT BENDER. The bender can be made locally from 0.125 diameter rod stock according to the dimensions shown in (B) of figure 13–13.

Maintenance of wafer-type switches which are included in many kinds of electronic equipment involves adjustment and cleaning. These operations are accomplished by the same procedures and by use of the same tools employed for relays.

MAINTENANCE OF HYDRAULIC AND PNEUMATIC EQUIPMENT

The maintenance and repair of hydraulic and pneumatic units in missiles and in missile test equipment pose no special problems if the instructions given in the appropriate maintenance publications are followed closely. However, there are two general precautions of importance which apply to work with fluid systems. These are the need for cleanliness in work areas, tools, and in the equipment; and the need for constant observance of safe work practices.

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The standard safety precautions applicable to hydraulic and pneumatic maintenance and repair are given in chapter 14 of this course. The need for cleanliness results from the fact that the moving parts of hydraulic and pneumatic devices are machined to very close tolerances and must be perfectly free from foreign matter. The smallest impurity introduced into these systems either from the work area or from tools can damage the precision components, impair the operation of the overall system, and cause a missile failure.

PERIODIC INSPECTIONS.—As aids in preventing impurities from entering missile fluid equipment, inspections are made at regular intervals of the auxiliary test equipments, particularly of those units which supply fluid for testing the missile and which charge it prior to flight. The minimum requirements for most hydraulic systems can be met by two kinds of inspections, a 25-hour and a 50-hour inspection.

After 25 hours of operation, the input and output filters of the system should be removed and examined. The filters are usually of the micronic type. In these, the elements cannot be cleaned. If these show signs of excessive collection of impurities, they must be replaced. The filter housings are cleaned carefully, and the filter elements replaced by new ones if this is necessary.

After 50 hours of operation, the air intake filters of systems containing air compressors are visually inspected. If dirty, the filter element is replaced. Similarly, the output air filter is removed, inspected, and replaced if necessary.

SYSTEM FLUSHING.—Flushing of the test equipment pumping system is performed to remove any contamination which might be present. This is always done after the initial installation and also following any major repair in which the principal connections have been broken and remade. When the initial installation has been completed and given an electrical checkout, or when the repairs have been completed, the equipment is turned on and the oil is allowed to circulate for 16 hours.

The equipment is then turned off and the oil is removed from the system. The dirty oil is discarded and the input oil filters are replaced. The reservoir is then filled with the

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recommended fluid, an example being Univis J–43, a red oil (AN–VVO–336, MIL–O–5606). When the reservoir is filled to the correct level, the system is then ready to supply oil to the missile for testing purposes or for charging the system for flight.

If the missile-borne hydraulic components become contaminated, they must be removed from the missile and reworked in a component repair shop. As explained in chapter 12, this type of repair is done only at a major shore repair station and not aboard ship or at a FASRon.

HYDRAULIC TROUBLESHOOTING.—Except for the electrohydraulic components, most troubleshooting in hydraulic systems is accomplished by visual means. The trouble of most frequent occurrence is some type of leak resulting from poor connections or from faulty O-rings. Normally, when connections show evidence of leaking fluid, tightening of the connections will be sufficient to stop the loss of fluid. When the leak results from a bad O-ring, it may be necessary to disassemble the unit and replace the ring. If any leak cannot be repaired by these methods, it is necessary to replace the component and return it to a repair activity.

CARE OF PNEUMATIC EQUIPMENT.—In general, the same periodic inspections and the basic precautions required for hydraulic systems are also valid for the maintenance of pneumatic equipment. The micronic filter elements of the system must be inspected for cleanliness and replaced at regular intervals; and the filter housing must be kept clean. Pneumatic units which become contaminated cannot be flushed as can hydraulic systems but must be disassembled and cleaned in the manner prescribed by the appropriate maintenance handbook.

Leaks in air or nitrogen systems can usually be found with the aid of a soap solution applied to the suspected connections or joints. The presence of a leak is revealed by the formation of bubbles. Tightening of a leaking connection or the replacement of the associated O-ring is usually sufficient to effect the needed repair.

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MISSILE LOGS, RECORDS, AND REPORTS

Missile Logs

Among the more important clerical duties of the personnel of a Guided Missile Division or a Guided Missile Shop are those of keeping a Shop Log and many Missile Logs.

A Shop Log is maintained on a job-order basis. When work is done on a missile, an entry is made in the Shop Log recounting the problem encountered; the nature of the work done; and new components incorporated; the resulting final status of the missile; and the date and time the work was finished. The senior petty officer of the check crew signs the log entry upon completion.

Each missile is accompanied by a MISSILE LOG, the purpose of which is to supply a complete and accurate account of all tests, repairs, or checkouts made on the missile. The entries must be kept up-to-date and are made by a representative of any test team performing work on the missile. The Missile Log is completed and submitted in accordance with the instructions of the bureau concerned as soon as the missile is expended.

Missile Records

The principal records kept by GF personnel within the G/M Division are (1) Missile Status File Cards, (2) Ordnance Expenditure Records, and (3) Missile Test Equipment Records.

MISSILE STATUS FILE CARDS.—These cards are initiated as soon as a missile is received and should contain the following information: the date of receipt; all work completed; all checks made; the history of the individual missile (including such items as arrested landings, catapult takeoffs, or any other significant captive-flight data); and the date of missile expenditure. The status file serves to record for future use information concerning malfunctions of equipment, unusual discrepancies, and the types of remedies employed.

ORDNANCE EXPENDITURE RECORDS.—These records supply an accounting of the history and expenditure of ordnance devices such as missile motors. In the case of missile motors,

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the record is kept by serial number, with which is associated an entry showing the date of receipt, all inspections made, and the date of expenditure. In the preparation of such records, the G/M Division must be guided by current directives issued by the bureaus concerned and by appropriate activities of the fleet.

MISSILE TEST EQUIPMENT RECORDS.—These are records pertaining to nonexpendable test equipments and are kept on an "as-occurring" basis. The record should indicate the dates of periodic checks; the dates and nature of all repairs made; all adjustments and calibrations accomplished; and any other data useful in maintaining the equipment in working condition. As in the case of ordnance records, detailed procedures for keeping these records must be in accord with instructions issued by the bureau or activity concerned.

Material Failure Reports

All naval activities operating and maintaining guided missiles are required to prepare and submit detailed reports concerning failures in many kinds of equipment. These include missile airframes and all missile electronic material, as well as small parts, components, assemblies, total equipments, and related materials. The data provided by the reports are required for use in the Navy Reliability Program. The purposes of the reports are (1) to supply accurate and current information concerning the kinds and numbers of specific failures, (2) to provide facts useful as guides in procurement of equipments and supplies, and (3) to give data pertaining to the reliability of existing equipment and indicating any need present for modification or redesign.

Two systems of reporting are employed as the working tools of the reliability program. These systems are based on the Electronic Failure Report (EFR) and the Failure, Unsatisfactory, or Removal Report (FUR). For each system a special report form has been designed to aid in rapid processing of the data, and the use of the correct form for a particular failure report is of considerable importance.

EFR AND FUR FORMS.—Electronic failures are reported by use of form DD 787. This form is a single sheet and is

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supplied in pads of 100. The complete instructions for its use and the requirements to be met by reports made with it are given by Instruction NavAer 00.58B.

The FUR system of reporting employs form NavAer 3069. These forms are supplied as eight-page sets with carbon interleaves; and all eight sheets are used for the majority of reporting applications. The first sheet of the set is available in pads of 100 for use as worksheets and also for reporting unsatisfactory conditions where a turn-in of material is not required.

Both the EFR and the FUR forms are supplied by regular publication supply sources and may be ordered on Publications and Forms Order Blank NavAer–140.

THE EFR SYSTEM.—In general, EFR's are required for all faults or failures of parts, components, or equipments of aviation electronic materials, including those of air-launched guided missiles. A form DD 787 is completed in each of the following conditions of electronic material.

1. When it fails to operate properly in its normal place of operation.

2. When it requires removal from the normal place of operation for replacement of parts, maintenance, adjustment, or repair.

3. When it is unsatisfactory for any reason, such as requiring excessive adjustment, maintenance, and/or removal due to inaccessibility for maintenance.

4. When it is unsatisfactory upon initial receipt from the supply system because of reasons such as requiring excessive man-hours to incorporate modifications, to make relubrications, or because it is in an inoperative condition.

Materials received from supply in damaged condition are not reported on form DD 787 but are properly reported on form DD6, Report of Damaged or Improper Shipment.

The EFR is not used when it becomes necessary to return a component or equipment to the supply system in exchange for a new item. In such cases, the FUR form, NavAer 3069, is required to provide the necessary accountability data. It is never necessary to complete both the FUR and the EFR forms for a single failure.

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THE FUR SYSTEM.—Operating activities are required to submit FUR's for all failures or unsatisfactory condition of aeronautical materials except those for which Electronic Failure Reports are submitted. The materials reported under the system include those of air-launched guided missiles and related equipment with the exception of electronic components which are not peculiar to a specific missile. A NavAer 3069 report is made for any part or equipment that has exhibited a malfunction, that has failed, or that has been removed from the missile system or from an assembly. It is not required for high-usage items such as nuts, bolts, washers, and similar materials.

A separate FUR is required for each item replaced, except when several similar items with the same stock number are replaced in the same unit. In this case, a single report suffices for all.

Under the FUR system, reporting is accomplished in several different ways. The principal types of reports are:

1. Those made on the single-sheet form used when turn-in of material to supply is not necessary.

2. Reports made with the regular multiple-sheet form, which is used when turn-in of material is required.

3. The amplified report, or AMPFUR, which is made on a single sheet and which includes additional amplifying information.

4. The priority AMPFUR (URGENT or FLIGHT SAFETY), which is submitted when priority investigation or corrective action is required.

PREPARATION AND SUBMISSION.—The preparation of EFR's and FUR's is usually accomplished by two classes of personnel. The form is made out by the technician who diagnoses the trouble or makes the necessary replacement or repair. In addition, each command normally contains a person who has been designated to review all failure reports to insure accuracy and completeness prior to mailing.

Classified EFR's and FUR's are mailed separately to the Bureau of Aeronautics (MA–61). Unclassified reports are mailed to the BuAer Reliability Center, NAS, Quonset

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Point, R. I. When both types of reports are included, they should be separated to expedite handling.

For complete instructions pertaining to the preparation of these reports, the reader is referred to Instruction NavAer 00.58B, the directions of which should be followed closely by persons submitting either of the two forms.

In all the procedures described in this chapter and the chapter preceding, perhaps the considerations of greatest importance are those of safety, both of personnel and of equipment. This subject is reserved for special treatment in the following chapter, which contains authorized precautions and safety rules applicable to the work of the missileman.

QUIZ

1. Operational, technical, and depot are three types of
   a. handbooks
   b. damage
   c. major overhaul
   d. maintenance
2. The primary technical duties of the GF include the
   a. adjustment, maintenance, and testing of guided missile radar and auxiliary equipment
   b. maintenance, adjustment, and testing of special test equipment only
   c. assembly and loading of guided missiles only
   d. assembly, adjustment, maintenance, and testing of guided missile systems and components
3. The list of equipment required, but not supplied in the *Missile Handbook* is found in the
   a. Tools and Test Equipment Section
   b. Missile Checkout Procedures Section
   c. General Information Section
   d. Component Repair Section
4. Missile schematics and parts layout diagrams in the *Missile Handbook* are found in the
   a. General Information Section
   b. Theory of Operation Section
   c. Component Repair Section
   d. Preparation of the Missile for Use Section

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5. The *Naval Aeronautic Publications Index* is divided into
   a. four parts
   b. three parts
   c. two parts
   d. one part with a supplement

6. The consolidated listing of all publications and forms which pertain to ordnance activities are contained in the
   a. *Naval Aeronautic Publications Indexes*
   b. *Index of Ordnance Publications*
   c. A. S. O. master index
   d. *BuOrd Manual*

7. In signal tracing, the outputs are checked with test instruments having a
   a. high impedance
   b. high power factor
   c. low impedance
   d. low power factor

8. In troubleshooting, the unit under test is supplied input test signals from
   a. special component test equipment
   b. the Nobatron
   c. the high-voltage power supply
   d. the oscilloscope

9. The flux used in soldering electronic and electrical circuits is
   a. soft flux
   b. hard flux
   c. acid flux
   d. rosin flux

10. Electric soldering irons are rated according to
    a. tip size
    b. radiation resistance
    c. voltage rating
    d. the quantity of heat dissipated by the heating element

11. Good connections in soldering result from
    a. using extra amounts of heat
    b. using special fluxes
    c. clean parts and careful techniques
    d. joints with thick layers of solder

12. Overheating of missile components while soldering is prevented by using
    a. a bus bar
    b. steel pliers
    c. a thermal shunt
    d. an insulation grip

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13. The process of fastening terminal lugs to the conductors is known as
    a. spiking
    b. swaging
    c. welding
    d. extruding
14. The colored dot on one side of the base of a subminiature tube signifies
    a. the tube is a triode
    b. pin one
    c. the plate lead
    d. tube type
15. The "Ordering Spare Parts" section is found in the
    a. *Illustrated Parts Breakdown*
    b. *Missile Log*
    c. component repair instructions.
    d. missile status cards
16. A resistor with the JAN designation of RC 42 GF 243 J has a resistance of
    a. 24 K ohms
    b. 245 ohms
    c. 400 ohms
    d. 42 ohms
17. A resistor with a resistance tolerance designator of K has a tolerance of
    a. 1%
    b. 20%
    c. 5%
    d. 10%
18. An axial-lead resistor with bands colored violet, black, yellow, and silver reading from left to right has a resistance of
    a. 7.04 ohms
    b. 704 ohms
    c. 700 K ohms
    d. 70 K ohms
19. The resistance tolerance of the resistor in question number 18 is
    a. 5%
    b. 10%
    c. 20%
    d. 0.1%
20. The capacitance value of a color coded JAN mica capacitor is in
    a. micromicrofarads
    b. microfarads
    c. millifarads
    d. farads

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21. The JAN designation of a fixed ceramic-dielectric capacitor is CC–25–SL–100–G. The SL designation indicates
   a. type of dielectric
   b. temperature characteristics
   c. capacitance value
   d. component type

22. Electrical brushes in rotating power equipment are cleaned with
   a. a wire brush
   b. MIL–2190 oil
   c. a lintless clean cloth
   d. carbon tetrachloride

23. A general precaution of importance which applies when working with fluid systems is
   a. temperature control of the work area
   b. close observation of the pressure
   c. proper clothing
   d. cleanliness of work area and equipment

24. When flushing a system the oil is allowed to circulate in the system for about
   a. 16 hours
   b. 2 hours
   c. 25 hours
   d. 48 hours

25. Contaminated missile hydraulic components are reworked at a
   a. ship's missile shop
   b. major shore repair station
   c. FASRon
   d. manufacturer's depot

26. The Shop Log is maintained by
   a. the Commanding Officer
   b. the Missile Officer
   c. Senior Petty Officer of the check crew
   d. the Log Yeoman

27. Information concerning malfunctions of equipment, unusual discrepancies, and the types of remedies employed are found in the
   a. Missile Log
   b. Missile Test Equipment Records
   c. Missile Expenditure Records
   d. Missile Status File Cards

28. Electronic failures are reported on form
   a. NavAer 140
   b. NavAer 3069
   c. DD 787
   d. NavAer 00.58B

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29. The FUR system reports are submitted for
    a. electronic failures only
    b. failures or unsatisfactory condition of aeronautical material
    c. the expenditure of missiles by firing
    d. the status of missiles on hand

30. Unclassified EFR's and FUR's are mailed to
    a. Reliability Center, NAS, Quonset Point, R. I.
    b. Status Board, BuAer, Washington, D. C.
    c. Supply Officer, Norfolk, Virginia
    d. BuOrd, Washington, D. C.

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CHAPTER 14

SAFETY PRECAUTIONS AND FIRST AID

INTRODUCTION

Most of the duties of the Aviation Guided Missileman require constant vigilance and regular observance of safety measures. The safety precautions which apply to the work and duty of the Aviation Guided Missileman include those concerning routine missile operations; work with electrical and electronic equipment; work involving the handling of explosive ordnance material; work done in and around aircraft; work in limited spaces, and in proximity to equipment capable of starting fire or generating noxious gases when overheated; the use of high-pressure liquid and pneumatic systems; and work done with hand and small power tools. In addition, the missileman is required to know the authorized methods for treating burns and for giving artificial respiration to persons suffering from electrical shock.

Because of the many specialized devices he uses, and because of the potential hazards in his work, the missileman should consider the formation of safe and intelligent work habits as being equal in importance to the development of his technical knowledge and skills. He should strive to exhibit the attitudes and practices which are characteristic of "safety mindedness." One of his objectives should be to become a safety specialist, trained in recognizing and correcting dangerous conditions and in avoiding unsafe actions.

This chapter, "Safety Precautions and First Aid," is in no way an exhaustive treatment of safety practices. Each missileman is expected to know and practice those safety precautions for each particular situation as set forth in local

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directives, in equipment maintenance manuals and in the *United States Navy Safety Precautions*, OpNav 34P1.

BASIC SAFETY PRECEPTS

Under the heading "Basic Precepts," the *United States Navy Safety Precautions* (OpNav 34P1) makes the following statement:

"Most accidents which occur in noncombat operations can be prevented if the full cooperation of personnel is gained and vigilance is exercised to eliminate unsafe acts."

This publication then gives the following safety precepts which apply to personnel in all types of activities:

"Each individual concerned shall strictly observe all safety precautions applicable to his work or duty.

"a. REPORTING UNSAFE CONDITIONS. Each individual concerned shall report any unsafe condition, or any equipment or material which he considers to be unsafe.

"b. WARNING OTHERS. Each individual concerned shall warn others whom he believes to be endangered by known hazards or by failure to observe safety precautions.

"c. PERSONNEL PROTECTIVE EQUIPMENT. Each individual concerned shall wear or use protective clothing or equipment of the type approved for the safe performance of his work or duty.

"d. REPORT INJURY OR ILL HEALTH. All personnel shall report to their supervisor any injury or evidence of impaired health occurring in the course of work or duty.

"e. EMERGENCY CONDITIONS. In the event of an unforeseen hazardous occurrence, each individual concerned is expected to exercise such reasonable caution as is appropriate to the situation."

BASIC SAFETY PRECAUTIONS FOR MISSILE WORK

Missile Handling

GENERAL SAFETY PRECAUTIONS.—All missile handling must be carried out in accordance with approved local safety regulations in force on shipboard, at depots, or wherever the work is accomplished. Detailed precautions must be observed, and specific instructions must be followed with each type of guided missile. These are given in the handbook or other classified publications pertaining to the missile.

Work areas must be kept clear of obstructions, loose cables,

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hose, and any unneeded equipment during missile assembly and testing. Only those persons engaged in the work in progress should be permitted in the work area or in the vicinity of the missile at these times.

All rocket motors and explosive units must be handled in strict accordance with standard Navy practices for ordnance materials.

Only authorized handling equipment should be used with any missile, or with any missile section, component, or related parts, including shipping crates and containers.

Care should be taken to see that all electrical equipment used in missile handling operations is adequately shielded and grounded.

UNCRATING, ASSEMBLY, AND DISASSEMBLY.—Care should be taken to avoid injury from sharp edges which are often present on nose assemblies, wings, and tail fins. After assembly, all dangerously sharp edges should be covered with guards.

Tools used for uncrating missile components during assembly must be of the type specified in the missile handbook.

Never attempt to force any unit; if it does not fit or function properly, determine the cause and correct it before proceeding.

Precautions With High-Pressure Fluid Systems

GENERAL SAFETY PRACTICES.—When any hydraulic unit is disassembled for inspection or repair, be sure that the workbench is thoroughly cleaned of dirt and metal filings.

Never use carbon tetrachloride, lacquer thinner, or similar liquids for cleaning hydraulic units. Use only the cleaning solvents or other materials specified in the missile handbook.

Keep the hands and other parts of the body well clear of exhaust streams when working with test equipment employing high pneumatic pressures.

PRECAUTIONS WHEN HANDLING OR CHARGING GAS BOTTLES.—The wing-servo units in many missiles are supplied with primary power by means of an accumulator charged from gas bottles, or cylinders, containing compressed air or

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nitrogen. The high pressures used in those units make it necessary that extreme caution be exercised by personnel charging the accumulators and gas bottles or handling the containers in which the gases are stowed.

1. When charging gas bottles, be sure that all personnel not required for the work are cleared from the area. Proper protective equipment including goggles must be worn by all persons during charging.

2. Never drop gas cylinders or permit them to strike each other violently.

3. When returning empty cylinders, be sure that all valves are closed, that valve protection caps are in place, and that the proper residual pressure is maintained.

4. Do not tamper with any safety device or valve on the container or the associated equipment.

5. Do not refill any container with gas unless such action has been specifically approved and then only in accordance with explicit instructions. Explosive mixtures may be obtained in cylinders containing traces of combustible gases when these are refilled with compressed air.

6. Do not use regulators, pressure gages, manifolds, and related equipment provided for a particular gas on cylinders containing a different gas.

7. Never discharge a cylinder into any device or equipment wherein the gas will be entrapped and build up pressure unless the cylinder is equipped with a pressure regulator or other device for controlling the pressure.

8. When testing for leaks in a gas container, use soapy water.

9. When it becomes necessary to drain cylinders containing toxic or irritant gases, be sure that there is no possible hazard to personnel or property. For these operations, personnel should be provided with protective clothing, goggles, and breathing masks.

ACCUMULATOR HANDLING AND CHARGING.—Pressure accumulator units in hydraulic systems must be charged with dry air (or nitrogen) and hydraulic fluid in strict accordance with the procedure given in the missile publication. Never charge an accumulator with oxygen.

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All hydraulic fluid and air charges must be discharged from accumulator units before the wing-control section is removed. High pressures, capable of causing injury to personnel and damage to equipment, exist at the connection between the wing section and the accumulator unit when the latter is charged with hydraulic fluid.

Safety Precautions for Systems Test

All missile test equipment must be operated by properly qualified personnel only. Before applying test pressures to the missile, be sure that all air and hydraulic connections are well secured. A loose connection is dangerous, since the pressures used are generally capable of causing serious injury and damage.

Check all missile ground wires to see that they are in place before starting a test.

Keep fingers and hands away from wings and fins when the control section of the missile is energized to avoid injury from moving surfaces.

Before hydraulically operated units are put into operation, be sure that all personnel not needed in the process are cleared from the area.

Upon completion of systems tests be sure that the air and hydraulic supplies have been turned off and bled before removing the lines from the missile.

Ordnance Precautions

Missile ordnance materials include rocket motors, igniters, fuzes, warheads, and in some cases, boosters, or auxiliary rockets. All of these units are potentially dangerous; and any particular unit must be handled in accordance with the specific procedures authorized for it in the appropriate publication. The following precautions are to be observed in addition to the detailed directions given in the handbooks of particular missiles.

General precautions.—All safety devices provided in ordnance units must be used exactly as designated. These devices must be kept in order and operative at all times.

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Changes, modifications, or additions to ordnance items must be made only upon explicit direction by the bureaus concerned.

No explosive assembly is to be used in any way or in any appliance except that which is designated by the proper authority.

HANDLING, FUZING, OR INSERTING IGNITERS IN ORDNANCE MATERIALS.—Electric igniters, VT fuzes, detonators, and electrically fired rocket motors must be carefully protected from radio-frequency emissions. None of these units should be exposed within FIVE FEET of any operating electronic transmitting equipment, including antennas and antenna leads. When the transmitting apparatus is a part of authorized test equipment or is a part of the weapon system, special instructions concerning its operation must be followed. No danger exists, however, from radio-frequency potentials with detonators of any type while they are completely enclosed in metal containers.

Warheads and fuzes must be protected from abnormally high temperatures. If exposed, they must be handled in accordance with current instructions of the bureau concerned.

Normally, warheads are issued unfuzed. Fuzes shall not be inserted until just prior to flight time. Fuzing shall not be accomplished near a magazine, but may be accomplished in handling rooms or spaces specially designated by competent authority. When fuzing takes place, missiles should be isolated from other ammunition as far as is practicable.

Be sure that the missile airframe is well grounded electrically at all times. Before connecting igniters in rocket motors, check the firing leads for stray or induced voltages and for static charge.

Before handling any piece of ordnance material, inspect the safety device to be sure that it is in the SAFE position. If not, the unit must be made safe by experienced personnel before further work is carried out.

Before connection in rocket motors, the igniter should be inspected to see that the case and safety switch are free

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from damage. If any is found, the entire assembly should be rejected.

Safety pins in fuzes, or any other device requiring removal or adjustment before flight, must be removed or adjusted only after the missile has been loaded on the launcher.

Missiles not expended on live runs must be made safe at the first opportunity in accordance with current instructions for the various ordnance assemblies.

PRECAUTIONS WITH ROCKET MOTORS.—No motor assembly that has been dropped should be fired. Care should be taken to avoid dropping or otherwise shocking the motor assembly, since the solid fuel is fragile and becomes dangerously explosive when broken.

Disposal of rejected motor assemblies and subassemblies must be made in exact accordance with local regulations governing the particular type of unit.

Never use power tools for any work on the motor nor apply heat to it or to any associated component.

Some rocket motors can be ignited by static charges carried by personnel or built up on ungrounded equipment. Be sure that the motor case is grounded during all handling operations.

In case of rocket motor misfire, personnel must not approach the rocket for at least 10 minutes, nor until the firing circuits are known to be open.

If, during handling, it is learned that any motor or booster is in the armed condition, the unit must be disarmed before proceeding with further activity.

STORAGE AND STOWAGE PRECAUTIONS.—Explosives and propellant devices must be stowed only in magazines which are specifically designated and approved and in which the temperature never exceeds safe values.

Warheads shall not be stowed with fuzes installed and fuzes shall be stored ONLY in specially designated fuze magazines not located adjacent to magazines containing high explosives.

Magazines in which ordnance materials are stored must be kept scrupulously clean and dry at all times. Nothing

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should be stored in any magazine except the designated materials and authorized magazine equipment.

Particular care must be taken to insure that no oily rags, waste, or other foreign materials capable of spontaneous ignition are present in magazines.

Naked lights, matches, or flame-producing apparatus must never be taken into ordnance magazines or into other spaces containing ordnance materials.

All explosives should be moved to safe storage before performing any work which may cause either abnormally high temperature or an intense local heat in a magazine or any compartment used as a magazine until normal conditions have been restored.

All ordnance materials are to be securely fastened in approved types of racks during storage. Removal from the racks should be accomplished by use of authorized handling equipment only; and before using this equipment, it should be checked to be sure that it is in proper working order.

Always check any component containing a safety and arming device (such as a rocket motor, a fuze, igniter, or booster) to be sure that it is in the SAFE condition before placing it in storage.

Ground wires must be attached to propulsion units in storage, in checkout, and while being transported from one area to another. (When a unit is moved, the ground connection can be made by use of a dragging chain.)

MISCELLANEOUS ORDNANCE PRECAUTIONS.—Flares (often used in missiles with command guidance as well as other types) and similar pyrotechnic materials must be kept, prior to use, in special pyrotechnic storage spaces or in pyrotechnic lockers on upper decks. When handling ordnance materials of this kind, care should be taken that the minimum amount possible is exposed at any given time.

All personnel working with chemical ammunition should be properly qualified and trained in the fundamentals of handling toxic chemicals, and should be familiar with the use of authorized handling equipment, including protective clothing and gas masks.

Launcher firing circuits should be tested only after deter-

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mining that rockets are not installed. All personnel should exercise care to keep clear of the possible exhaust paths of rockets at all times.

Precautions When Working Near Aircraft

In addition to all local orders and directives, the following precautions should be observed:

Remain constantly on the alert to avoid injury to or damage to person or property caused by slipstream, jet blast, or rocket blast.

Stay clear of jet intakes and propellers.

Do not smoke or bring any type of open flame within 50 feet of any parked aircraft. Remember that vapor from aviation fuel can be ignited in a number of ways—by lighted cigarettes, by static discharges, and by sparks from tools or from electrical and electronic equipment.

See that combustible materials such as rags and clean waste are stowed in metal containers. Used waste and rags should never be discarded near aircraft but should always be put in plainly marked METAL receptacles.

SAFETY PRECAUTIONS FOR MISSILE ELECTRONIC WORK

Most of the safety rules for electrical work also apply to the operation, repair, and maintenance of missile electronic equipment. In addition, special precautions must be taken against the high potentials normally present in electronic devices; against dangerous effects of radiated energy; and against possible injury when handling electronic component parts.

The standard safety measures to be taken by personnel engaged in electronic work include those pertaining to personal protection, to work done on electronic equipment, and to safety from fire.

Personal Protection

CLOTHING.—The following general rules apply to clothing worn during electrical work:

1. Do not work on electronic apparatus with wet hands

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or while wearing wet clothing or any clothing which is loose and flapping.

2. When working within four feet of electronic equipment do not wear clothing with exposed zippers, metal buttons, or any type of metal fastener. No flammable articles, such as celluloid cap visors, should be worn.

3. Personnel should remove rings, wristwatches, bracelets, and similar metal articles when working on or within four feet of electronic equipment having exposed current-carrying parts.

4. When working on or near electronic apparatus personnel shall wear high-cut shoes with sewed soles or safety shoes with nonconducting soles, if these are available. The use of thin-soled shoes and those with metal plates or hobnails is prohibited.

PROTECTIVE EQUIPMENT.—Danger signs and suitable guards should be provided to warn all personnel wherever live parts of electric circuits and equipment are exposed when the voltages involved are 50 volts or greater.

Insulating floor covering should be used in work areas where electronic equipment is serviced, particularly where the deck or walls are of metallic construction.

Interlocks, overload relays, fuses, and other protective devices should never be altered or disconnected except for replacement, nor should any safeguard circuit be modified without specific authorization.

Metal enclosures for electrical and electronic equipment must be kept effectively grounded.

HIGH-VOLTAGE PRECAUTIONS.—Adjustment, repair, and maintenance of missile radars, radio units, and test equipment must be done only by duly authorized personnel.

Adjustment of transmitters and other high-voltage equipment should not be attempted while the motor-generator is running or while the rectifiers are energized, unless the adjustments can be made by the use of exterior controls provided for the purpose.

Except in emergencies or when it is considered essential by the proper authority, repairs should not be made on energized electronic equipment. If such work is necessary,

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it should be undertaken only by experienced personnel; and all safety precautions pertaining to work on energized circuits should be observed.

PRECAUTIONS AGAINST ELECTRIC SHOCK.—Adherence to the rules concerning clothing and protective equipment is essential in areas where electrical work is done and serves as an aid in preventing shock. Other safety precautions to be taken are as follows:

1. Never work alone near high-voltage equipment.
2. Exercise caution when using tools with metal parts, metal tapes, cloth tapes with embedded metal threads, and cleaning equipment containing metal parts. None of these should be used in any area within four feet of electronic equipment or wiring having exposed current-carrying parts.
3. Any person working on or around electronic circuits should be very careful to keep his attention from wandering and becoming diverted from the work.
4. Exercise as much care to avoid contact with low voltages as with high voltages. Never take a shock intentionally from any source; this is a dangerous practice and is strictly forbidden. If a particular circuit operates normally at 600 volts or less, and it is necessary to determine whether it is energized, use a voltmeter, voltage tester, or other suitable indicating instrument.
5. Before the terminals of apparently deenergized equipments are touched, short them together and to ground, using a suitably insulated shorting device.

Electronic Equipment

RADIO-FREQUENCY CIRCUITS.—When nearby transmitting equipment is in operation, workers should be on the alert to avoid shock and burns resulting from contact with antennas, antenna leads, and other exposed parts.

Special precautions concerning ordnance material should be observed before "firing" transmitters.

Radar and radio transmitters should never be operated within 75 feet of where fueling operations are in progress in aircraft. Also, no transmitter should be energized within an aircraft following fueling until the hull has been thor-

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oughly ventilated and cleared of fumes, or at any time when gasoline vapors appear to be present.

Transmitting antennas of high-frequency equipment must not be energized whenever they are less than 50 feet from the following hazards:

1.. Guns with electric firing circuits, when not installed in shielded mounts or turrets, either during the process of loading or in the loaded condition.

2. Ammunition fitted with electric primers, when not in a mount, turret, or an ammunition container.

3. Unshielded flare circuits in aircraft when the flares are installed.

4. Oil-fueling operations during the intervals when the metallic hose connections are either made or broken.

Crystal diodes.—Static electric charges carried by the worker can burn out crystal diodes, which are often used in missile radar receivers. When installing a crystal, the cartridge should be held with the fingers touching one end only. The hand holding the unit should then'be grounded against the missile airframe before the end of the crystal is brought into contact with the holder.

Capacitors.—Before a worker touches a capacitor, either connected in a deenergized circuit or disconnected entirely, he should always short-circuit the terminals to be sure that the capacitor is completely discharged. A suitably insulated lead or a grounding bar should be used for this purpose. Grounded shorting prods should be attached permanently to workbenches where electronic units are regularly serviced or overhauled.

Before missiles are loaded on aircraft launching racks, all electrical power in the plane, including the guidance radar power supply, should be turned off. In many systems, high voltages exist at the umbilical plug; and unless proper precautions are taken, shock and shorting hazards are present when the missiles are installed.

Care should be taken when using tools made of magnetic materials near radar magnetrons, since the tool can be pulled by the magnet into contact with dangerous, high-voltage circuits.

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Fuses.—Fuses should be removed and replaced only after the circuit has been completely deenergized. When a fuse "blows," it should be replaced only with a fuse of the same current rating. When possible, the circuit should be checked carefully before making the replacement since the burned-out fuse usually results from a circuit fault.

Switches.—As a general rule, electronic equipment must be deenergized before work such as overhaul or repair is performed. The power source must be disconnected from the equipment by opening the main or branch supply switches, circuit breakers, or cutouts so as to eliminate completely any possibility of current flowing to the device.

Cathode-ray tubes.—The principal hazard when handling large cathode-ray tubes is the possibility of implosion, or the collapse of the glass envelope under atmospheric pressure. The tubes are not dangerous if properly handled; but if they are struck, dropped, scratched, or treated carelessly, they can well become an instrument of severe injury or even death. During installation or removal of these tubes, the following precautions should be taken:

1. Wear goggles to protect the eyes; fracture of the envelope combined with vacuum within the tube can result in flying glass particles.
2. Wear suitable gloves to protect the hands.
3. Be sure that no part of the body is exposed directly to possible glass splinters. Do not handle glass fragments since the coating on some tubes is poisonous and can enter the blood stream through cuts in the skin.
4. When the tube is needed, remove it from the packing box with caution, taking care not to strike or scratch the envelope or to expose it to possible damage. Insert the tube into the equipment socket, using moderate pressure and without jiggling it. Use the same procedure when removing the tube from the equipment.
5. If the tube must be set down, place the tube face down on a clean, soft padding. Avoid standing directly in front of the tube face since implosion often causes fragments to be propelled forward with great force.

Selenium rectifiers.—When selenium rectifiers burn out,

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fumes of selenium dioxide are liberated, causing an overpowering stench. The fumes are poisonous and should not be breathed. When a rectifier burns out, deenergize the equipment immediately, ventilate the compartment, and allow the damaged unit to cool before attempting any repairs. If possible, remove the equipment containing it out of doors. Do not touch or handle the defective rectifier while it is still hot, since a skin burn might result through which some of the selenium compound could be absorbed.

BATTERY PRECAUTIONS.—When working with batteries, precautions must be taken against shock and accidental shorting of the terminals, and against the possibility of injury resulting from contact with the electrolyte. The standard safety measures which apply in most cases include the following:

1. TOOLS. Use tools with insulated handles when removing or replacing batteries.

2. INSTALLATION. When replacing a battery which has one terminal grounded, remove the grounded terminal first and do not reconnect it until the new battery is in place and the other connections have been made.

3. ACID ELECTROLYTE. When preparing or handling solutions of sulfuric acid for use in lead-acid cells, observe the following precautions:

a. Never pour water into acid. The acid must be poured slowly into the water.

b. Guard the eyes and skin from splashing acid.

c. Do not store sulfuric acid in places where freezing temperatures are possible.

d. Keep the electrolyte in the cells at a level just above the separators.

4. ALKALINE ELECTROLYTE. In missile systems, battery cells containing corrosive alkaline solutions are often used. Examples are silver-zinc and nickle-cadmium batteries, in both of which the electrolyte is a solution of potassium hydroxide (KOH). This solution is active chemically; and extreme care should be taken to avoid spilling or splashing it on the skin, on clothing, or on surrounding equipment. If this occurs, the affected areas should be flushed immediately

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with large quantities of water. Afterwards, the chemical can be neutralized with a weak (10%) solution of acetic acid, if this is available.

Preparation of electrolyte should be done only by experienced personnel.

All mixing should be done in heat-resistant, plastic jars; and every precaution should be taken to prevent high temperatures from developing in the solution.

Constant stirring is necessary, using a monel metal paddle.

The solution should be stored in hermetically sealed, plastic containers; and these should not be opened until the electrolyte is needed for filling the cells.

CLEANING.—The following general rules apply when cleaning electronic and electrical equipment:

1. Alcohol, benzene, gasoline, and similar flammable liquids should never be used as cleaning agents, either on energized or deenergized apparatus. The use of alcohol is especially undesirable since it not only constitutes a fire hazard but it also results in damage to many kinds of insulation.

2. Never use carbon tetrachloride as a cleaning solvent. Unlike alcohol, it is not a possible source of fire; it is hazardous because of the dangerous effects of breathing its vapors. Careless use of carbon tetrachloride may result in headache, dizziness, and nausea. If the fumes are breathed in poorly ventilated compartments, the result may be loss of consciousness or even death.

3. When "blowing out" equipment with compressed air, use rubber hose or other suitable insulated hose as air lines. Care should be exercised that the pressure used is not excessive in terms of the delicacy of the equipment being "blown out," and the air should be free from moisture. Never turn compressed air on yourself or on others since it can cause serious injury.

Electrical Fires

General cleanliness of the work area and of electronic apparatus is essential for the prevention of electrical fires. Oil, grease, and carbon dust can be ignited by electrical arcing;

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hence, electronic equipment should be kept absolutely clean and free of all such deposits.

Volatile liquids, such as gasoline, insulating varnish, lacquer, turpentine, and kerosene, are dangerous when exposed near operating electrical or electronic units. When these liquids are used in compartments containing nonoperating equipment, be sure that there is sufficient ventilation to avoid an accumulation of fumes and that all fumes are cleared before the equipment is energized.

In case of fire occurring in or around electronic apparatus, the following steps should be taken:

1. Deenergize the equipment.
2. Call the Fire Department.
3. Control the fire as far as possible with the correct type of fire fighting equipment until the Fire Department arrives.
4. Report the fire to the appropriate authority.

For combating electrical fires, use only dry-chemical carbon dioxide (CO_2) extinguishers, or other types authorized for class C fires (those involving electrical devices). Carbon tetrachloride should never be used for fire fighting since it changes to phosgene (a poisonous gas) upon contact with hot metal; and even in open air, this gas creates a hazardous condition. The application of water to electrical fires is dangerous; and foam-type extinguishers should not be used since the foam is electrically conductive.

In case of cable fires in which the inner layers of insulation are burning, the only positive method of preventing the fire from running the length of the cable is to cut it and separate the two ends.

SAFETY WHEN USING TOOLS

As a general precaution, be sure that all tools used conform to Navy standards as to quality and type; and use each tool only for the purpose for which it is intended. All tools in active use should be maintained in good repair, and all damaged or nonworking tools are to be returned to the toolkeeper.

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Hand tools.—Care must be taken when selecting pliers, side cutters, or diagonal cutters. Pliers or cutters should never be used on nuts or pipefittings. Always hold the pliers or cutters so that the fingers are not wrapped around the handle in such a way that they can be pinched or jammed if the tool slips. When cutting short pieces, take care that parts of the work do not fly and cause injury. Never put extensions on tool handles to increase leverage.

When selecting a screwdriver for electrical work, be sure that it has a nonconducting handle. The screwdriver selected should be of the proper size to fit the screw and should never be used as a substitute for a punch or a chisel. The points of screwdrivers can be kept in proper shape with a file or a grinding wheel.

Use wrenches only if they are right for the job and only if they are in good condition. An adjustable wrench should be faced so that the movable jaw is located forward in the direction in which the handle is to be turned.

Portable power tools.—All portable power tools should be inspected before use to see that they are clean, well oiled, and in the proper state of repair. The switches should operate normally, and the cords should be clean and free of defects. The case of any electrically driven power tool should be well grounded; and sparking electric tools should never be used in places where flammable gases or liquids or exposed explosives are present.

Drills must be straight, undamaged, and properly sharpened. Tighten the drill securely in the chuck using the key provided; never secure it with pliers or with a wrench. It is important that the drill be set straight and true in the chuck. The work should be firmly clamped and, if of metal, a center punch should be used to score the material before drilling is started.

Be sure that power cords do not come in contact with sharp objects. The cords should not be allowed to kink, nor should they be allowed to come in contact with oil, grease, hot surfaces, or chemicals. When cords are damaged, they should be replaced instead of being patched with tape.

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FIRST AID

Treatment for Electrical Shock

Electric shock is a jarring, shaking sensation resulting from contact with high-voltage circuits or from the effects of lightning. The victim usually feels that he has received a sudden blow; and if the voltage is sufficiently high, the victim drops down unconscious. Severe burns may appear on the skin at the place of contact; and muscular spasm can occur, causing him to clasp the apparatus or wire which caused the shock and to become unable to turn it loose.

The following procedure is recommended for rescue and care of shock victims:

1. Remove him from electrical contact at once, but DO NOT ENDANGER YOURSELF. This can be done (1) by throwing the switch if it is nearby; (2) by cutting the cable or wires to the apparatus, using an ax with a wooden handle while taking care to protect your eyes from the flash when the wires are severed; (3) by use of a dry stick, rope, leather belt, coat, blanket, or any other nonconductor of electricity.
2. Determine whether the victim is breathing. If he is, keep him lying down in a comfortable position. Loosen the clothing about his neck, chest, and abdomen so that he can breathe freely. Protect him from exposure to cold, and watch him carefully.
3. Keep him from moving about. In this condition, the heart is very weak, and any sudden muscular effort or activity on the part of the patient may result in heart failure.
4. Do not give stimulants or opiates. Send for a medical officer at once and do not leave the patient until he has adequate medical care.
5. If the victim is not breathing, it will be necessary to apply artificial respiration without delay, even though he may appear to be lifeless.

Resuscitation From the Effects of Electric Shock

Artificial respiration is the process of promoting breathing by mechanical means. It is used to resuscitate persons whose breathing has stopped, not only as a result of electric

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shock, but also from causes such as drowning, asphyxiation, strangling, or the presence of a foreign body in the throat.

When a shock victim is to be revived, begin artificial respiration as soon as possible. If there is any serious bleeding, stop it first, but don't waste time on anything else. Seconds count; and the longer you wait to begin, the less are the chances of saving the victim.

The approved method of artificial respiration is the back-pressure, arm-lift technique illustrated in figure 14–1.

Place the victim in the face-down, or prone, position. Bend both his elbows and place one of his hands on the other. Turn his face so that it is resting on his hands. Quickly sweep your fingers through his mouth to clear it out

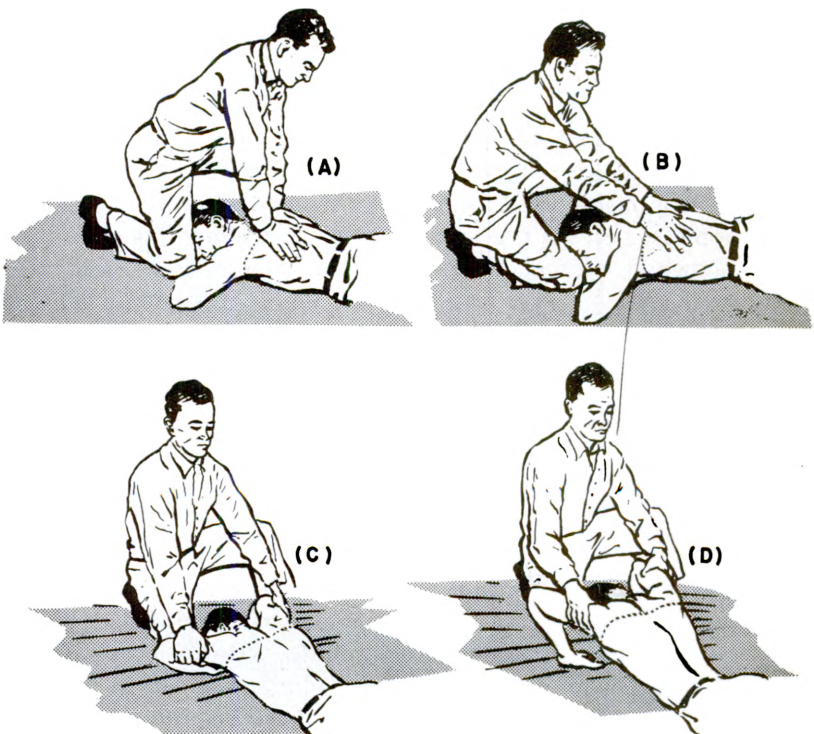

Figure 14–1.—The back-pressure, arm-lift method of artificial respiration.

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and be sure that the throat is open. With the same movement, bring the tongue forward so that it cannot stop the air passage.

Kneel at the victim's head, facing him. Kneel on either knee, or on both—whichever is most comfortable. Next, place your hands on his midback, just below the shoulder blades, so that the fingers are spread downward and outward and the thumb tips almost touching. This phase is shown in (A) of figure 14–1.

Rock forward until your arms are approximately vertical; and allow the weight of the upper part of your body to exert a slow, steady pressure on your hands until firm resistance is met. This action, shown in (B) of figure 14–1, causes the chest to be compressed so that air is forced out of the lungs. Keep your elbows straight and your arms almost vertical so that the pressure is exerted downward.

Be very careful to avoid exerting sudden or excess pressure, and be sure that your hands are not too high up on the victim's back or on his shoulder blades. Release the pressure quickly. "Peel" your hands from his ribs without any extra push. Then rock backward and allow your hands to come to rest on the victim's arms just above his elbows, as shown in (C) of figure 14–1. As you rock backward, draw his arms upward and toward you. Keep your arms nearly straight, as shown in (D) of the same figure.

Lift the victim's arms until you feel resistance and tension at the shoulders. The arm lift pulls on the chest muscles, arches the back, and relieves the weight on the chest, thus pulling air into the lungs. Next, lower the arms, and you have completed one full cycle.

The complete cycle can be chanted to help you keep the rhythm—"Place . . . Swing forward . . . Swing back . . . Lift." Keep this rhythm without stopping once you have begun. The four steps should take about 5 or 6 seconds, allowing 10 or 12 cycles per minute. Don't break the rhythm no matter what else is being done, such as:

1. Keeping the victim warm. If someone is there to help you, have him wrap the patient in clothing or a blanket. This can be done between cycles.

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2. Loosening his belt or tight clothing. Your helper can do this too.

3. Moving the victim. This is to be done only if you must, because of foul weather, fire, or other hazard. After he is breathing on his own, he may be moved, but only in a lying-down position.

When resuscitating a shock victim by artificial respiration, don't give up too soon. Sometimes it takes several hours. Be certain that all chance of saving him is gone before you think of stopping.

Keep watching the patient even after he starts to breathe again. If he stops, you must start artificial respiration again immediately. Keep him lying down and warm, even after he revives.

Treatment of Electrical and Thermal Burns

In administering first aid for burns, the objectives are to relieve the pain, to make the patient as comfortable as possible, to prevent infection, and to guard against his going into a state of shock which sometimes accompanies burns of a serious nature.

The greatest pain from a burn is caused by the movement of air over the damaged area. As a first step, cover the burn with some substance which will exclude the air. When the skin is merely reddened and is not broken, the burned area may be covered with a coating of vaseline. Never put iodine on a burn; and do not apply an antiseptic or a powder. Do not put cotton directly on the burn since it will stick and cause further injury.

If the skin is blistered or if the flesh is cooked and charred, secure the services of a medical officer or a corpsman as soon as possible. If medical aid cannot be obtained in a short time, proceed to dress the burned areas as follows:

1. Remove charred materials from the injured surfaces, taking care not to break any blisters which may be present. If clothing is stuck to any part of the surface, do not pull it loose, but cut around the cloth and let it stay attached.

2. Apply thin pieces of sterile vaseline gauze directly over the burned areas.

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3. Apply cotton wadding or gauze fluffs over the top of the gauze to give the dressing bulk.

4. Apply elastic bandages to make a snug pressure dressing.

5. Have the patient transferred to a hospital as soon as possible.

QUIZ

1. Authorized safety precautions require that electric igniters, detonators, rocket motors, and fuzes shall not be exposed within a certain number of feet from any operating transmitter. Which of the following is the number specified?
   a. 2
   b. 3
   c. 5
   d. 10

2. The principal hazard when handling large cathode-ray tubes is the possibility of
   a. explosion
   b. implosion
   c. alpha-ray exposure
   d. beta-ray exposure

3. NAVY SAFETY PRECAUTIONS require that during refueling of aircraft, radar equipment must not be operated within ________ feet of the plane.
   a. 25
   b. 50
   c. 75
   d. 100

4. Danger signs should be provided to warn all personnel where live parts of electrical circuits are exposed and where the voltages involved are at least ________ volts.
   a. 1,000
   b. 500
   c. 50
   d. 25

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5. A standard practice when replacing blown fuses is to
   a. replace with fuse of amperage rating within 20 percent of blown fuse
   b. completely deenergize circuit before replacing
   c. have assistant stand by gear with fire bottle
   d. replace with larger fuse until cause of overload has been determined

6. Rocket motors which have been dropped shall be
   a. fired as soon as possible
   b. discarded in accordance with local regulations
   c. repaired by authorized personnel
   d. checked on rocket motor test stand

7. The first thing to do after removing an electrical shock victim from electrical contact is to
   a. check pulse
   b. check for breathing
   c. cover with blanket
   d. make victim comfortable

8. When mixing sulfuric acid and water
   a. pour water into acid
   b. pour acid and water into container at same time
   c. pour acid into water
   d. insure that both are below 60° F.

9. A neutralizer for alkaline electrolyte is
   a. water
   b. baking soda
   c. hot concentrated solution of sulfuric acid
   d. a weak solution of acetic acid

10. When selenium rectifiers have burned out,
    a. remove immediately from equipment using special gloves
    b. immediately disconnect from electrical circuit
    c. immediately douse with CO_2
    d. ventilate the compartment

11. Carbon tetrachloride should never be used to clean electronic equipment for which of the following reasons?
    a. Its use creates a fire hazard.
    b. It damages most kinds of insulation.
    c. It is corrosive and can injure personnel and damage equipment.
    d. It is hazardous to personnel because of the dangerous effects of breathing its fumes.

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12. The type of tools used for uncrating and assembling missile components will be specified in the
   a. *Missile Handbook of Service Instructions*
   b. *Missile Log*
   c. *Missile Test Equipment Handbook*
   d. *Hand Tools Manual*

13. Before hydraulically operated units are put into operation
   a. hydraulic fluid temperature should be checked
   b. all personnel not needed in the process should be cleared from the area
   c. hydraulic fluid level should be checked
   d. all O-rings should be checked

14. All missile handling must be carried out in accordance with
   a. *BuOrd Manual*
   b. *BuShips Manual*
   c. *BuAer Manual*
   d. approved local safety regulations

15. Explosives and propellant devices must be stowed
   a. in the open
   b. next to missile repair shop
   c. in temperature controlled spaces
   d. completely assembled with other components of missile

16. According to Navy Safety Regulations, transmitting antennas in high-frequency equipment must not be energized when they are less than __________ feet from ammunition fitted with electric primers not in a mount, turret, or an ammunition container.
   a. 25
   b. 50
   c. 75
   d. 100

17. __________ is/are used on an electrical fire.
   a. Foam type extinguishers
   b. CO_2 extinguishers
   c. Soda acid extinguishers
   d. Pure water

18. Normally, fuzes shall be inserted in warheads
   a. at the factory
   b. when missile is under test
   c. just prior to flight time
   d. any time

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19. When administering first aid for burns, any clothing stuck to the burned area should be
    a. removed by the use of distilled water
    b. removed by the use of peroxide
    c. removed by the use of baby oil
    d. left on burn

20. When testing for leaks in a gas container, use
    a. soapy water
    b. clear water
    c. alcohol
    d. the smell test

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APPENDIX I

AN NOMENCLATURE SYSTEM

The AN letter-number system is used to identify the various kinds and models of electronic apparatus employed by the Army, the Navy, and the Air Force. Separate types of designations are used for complete installations of a particular equipment and for major components of the complete equipment. The basic designation for a complete installation is considered first.

An indicator for a complete installation begins with the letters AN. This is followed by a slant bar and a three-letter group. The letters AN are an abbreviation for Army–Navy. The three letters of the second group give the general nature of the installation, the type of equipment, and the purpose of the equipment, respectively. Following the three-letter group is a number which indicates the specific model of the equipment. An example of a basic designation is AN/DSM–10. The letters following the slant bar have the meanings given in table 1.

Using the example AN/DSM–10, the symbols are interpreted as follows: AN means "Army–Navy" and signifies a complete installation. In the three-letter group, the first letter, D, in the first or "Installation" column, indicates pilotless carrier. The second letter, S, is in the "Type of Equipment" column; there, it indicates special types or combination of types equipment. The letter M in the "Purpose" column refers to maintenance and test assemblies. Hence, the AN/DSM–10 is a pilotless carrier special maintenance or test assembly.

Table 1.—Set or equipment indicator letters

Installation	Type of equipment	Purpose
A—Airborne (installed and operated in aircraft).	A—Invisible light, heat radiation.	A—Auxiliary assemblies (not complete operating sets).
B—Underwater mobile, submarine.	B—Pigeon.	B—Bombing.
D—Pilotless carrier.	C—Carrier.	C—Communications (receiving and transmitting).
F—Fixed.	D—Radiac.	D—Direction finder.
G—Ground, general ground use (includes two or more ground installations).	E—Nupac (nuclear protection and control).	E—Ejection and/or release.
K—Amphibious.	F—Photographic.	G—Fire control or searchlight directing.
M—Ground, mobile (installed as operating unit in a vehicle which has no function other than transporting the equipment).	G—Telegraph or teletype.	H—Recording and/or reproducing (graphic, meteorological, and sound).
	I—Interphone and public address.	M—Maintenance and test assemblies (including tools).
	J—Electromechanical (not otherwise covered).	
	K—Telemetering.	
	M—Meteorological.	

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Table 1.—Set or equipment indicator letters—Continued

Installation	Type of equipment	Purpose
P—Pack or portable (animal or man).	N—Sound in air.	N—Navigational aids (including altimeters, beacons, compasses, racons, depth sounding, approach and landing).
S—Water surface craft.	P—Radar.	Q—Special or combination of purposes.
T—Ground, transportable.	Q—Sonar and underwater sound.	R—Receiving, passive detecting.
U—General utility (includes two or more general installation classes, airborne, shipboard, and ground).	R—Radio.	S—Detecting and/or range and bearing.
V—Ground, vehicular (installed in vehicle designed for functions other than carrying electronic equipment, such as tanks).	S—Special types (magnetic, etc.) or combination of types.	T—Transmitting.
W—Water; surface and undersurface.	T—Telephone (wire).	W—Control.
	V—Visual and visible light.	X—Identification and recognition.
	W—Armament (peculiar to armament, not otherwise covered).	
	X—Facsimile or television.	

ADDITIONAL DESIGNATORS

In order to identify experimental equipment, a designator is added in parentheses to the basic symbols. An example is AN/DSM–10 (XB–1). The letter X within the parentheses indicates experimental equipment, the second letter identifies the research organization carrying out the experimental development, and the number indicates the particular set developed. When the set has been accepted for general use, the experimental designator is dropped and the basic symbols are used thereafter. A set designed for training purposes is assigned type numbers as follows:

Equipment designed to train personnel in the use of a specific model is assigned a designator consisting of the basic set symbol followed by a dash, the letter T, and a number. For example: Radio Training Set AN/ARC–6A–T1 is the first training set associated with Radio Set AN/ARC–6A.

Models designed to train personnel in the use of general types of equipment are assigned the basic type indicator followed by a dash, the letter T, and a number. For example: Radio Training Set AN/ARC–T1 is the first training set used for instruction in the general use of airborne radio communication installations.

The number following the letters of the second group is the model number of the assembly. If the basic model is modified, the new model is given an additional letter such as A, B, or C following the model number. For example, AN/DSM–10A would be a modified version of the basic AN/DSM–10 model. The next modification is labeled AN/DSM–10B.

When the system just described is applied to subassemblies or major components of the complete installation, the designation is formed by

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replacing the letters AN with a letter-number group which indicates the type and model of component in question. For example, a power supply unit used with AN/DSM–10 is designated PP–1207/DSM–10. Test equipment used with a particular installation is also designated in the same general manner. A test set, Model 862, used with AN/DSM–10 is designated TS–862/DSM–10. Table 2 is a table of component indicators which are applied to the subassemblies or major components.

Table 2.—Component indicators

Comp. ind.	Family name	Examples of use (not to be construed as limiting the application of the component indicator)
AB	Supports, Antenna	Antenna mounts, mast bases, mast sections, towers, etc.
AM	Amplifiers	Power, audio, interphone, radio frequency, video, electronic control, etc.
AS	Antennas, Complex	Arrays, parabolic type, masthead, etc.
BA	Battery, primary type.	B batteries, battery packs, etc.
BB	Battery, secondary type.	Storage batteries, battery packs, etc.
C	Controls	Control box, remote tuning control, etc.
CG	Cable Assemblies, RF	RF cables, waveguides, transmission lines, etc. with terminals.
CK	Crystal Kits	A kit of crystals with holders.
CM	Comparators	Compares two or more input signals.
CN	Compensators	Electrical and/or mechanical compensating, regulating, or attenuating apparatus.
CP	Computers	A mechanical and/or electronic mathematical calculating device.
CR	Crystals	Crystal in crystal holder.
CU	Couplers	Impedance coupling devices, directional couplers, etc.
CV	Converters (electronic).	Electronic apparatus for changing the phase, frequency, or from one medium to another.
CW	Covers	Cover, bag, roll, cap, radome, nacelle, etc.
CX	Cable Assemblies, Non-RF.	Non-RF cables with terminals, test leads, also composite cables of RF and non-RF conductors.

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Table 2.—Component indicators—Continued

Comp. ind.	Family name	Examples of use (not to be construed as limiting the application of the component indicator)
CY	Cases and Cabinets	Rigid and semirigid structure for enclosing or carrying equipment.
DA	Load, Dummys	RF and non-RF test loads.
DT	Detecting Heads	Magnetic pickup device, search coil, hydrophone, etc.
DY	Dynamotors	Dynamotor power supply.
F	Filters	Band-pass, noise, telephone, wave traps, etc.
FR	Frequency Measuring Device.	Frequency meters, tuned cavity, etc.
G	Generators, Power	Electrical power generators without prime movers. (*See* PU & PD.)
HD	Air Conditioning Apparatus.	Heating, cooling, dehumidifying, pressure, vacuum devices, etc.
ID	Indicators, Non-Cathode-Ray Tube.	Calibrated dials and meters, indicating lights, etc. (*See* IP.)
IL	Insulators	Strain, stand-off, feed-through, etc.
IM	Intensity Measuring Devices.	Includes SWR gear, field intensity and noise meters, slotted lines, etc.
IP	Indicators, Cathode-Ray Tube.	Azimuth, elevation, panoramic, etc.
J	Junction Devices	Junction, jack and terminal boxes, etc.
KY	Keying Devices	Mechanical, electrical, and electronic keyers, coders, interrupters, etc.
MD	Modulators	Device for varying amplitude, frequency or phase.
ME	Meters, Portable	Multimeters, volt-ohm-milliammeters, vacuum tube voltmeters, power meters, etc.
MF	Magnets or Magnetic Field Generators.	Magnetic tape or wire eraser, electromagnet, permanent magnet, etc.
MK	Miscellaneous Kits	Maintenance, modification, etc., except tool and crystal. (*See* CK, TK.)
ML	Meteorological Devices.	Barometer, hygrometer, thermometer, scales, etc.
MT	Mountings	Mountings, racks, frames, stands, etc.
MX	Miscellaneous	Equipment not otherwise classified. Do not use if better indicator is available.

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Table 2.—Component indicators—Continued

Comp. ind.	Family name	Examples of use (not to be construed as limiting the application of the component indicator)
O	Oscillators	Master frequency, blocking, multivibrators, etc. (For test oscillators, *see* SG.)
OA	Operating Assemblies	Assembly of operating units not otherwise covered.
OS	Oscilloscope, Test	Test Oscilloscopes for general test purposes.
PP	Power Supplies	Nonrotating machine type such as vibrator pack, rectifier, thermoelectric, etc.
PU	Power Equipments	Rotating power equipment except dynamotors. Motor-generator, etc.
R	Receivers	Receivers, all types except telephone.
RE	Relay Assemblies	Electrical, electronic, etc.
RF	Radio Frequency Component.	Composite component of RF circuits. Do not use if better indicator is available.
RG	Cables, RF, Bulk	RF cable, wave guides, transmission lines, etc. without terminals.
RT	Receiver and Transmitter.	Radio and radar transceivers, composite transmitter and receiver, etc.
SA	Switching Devices	Manual, impact, motor driven, pressure operated, etc.
SG	Signal Generators	Test oscillators, noise generators, etc. (*See* O.)
SM	Simulators	Flight aircraft, target, signal, etc.
SN	Synchronizers	Equipment to coordinate two or more functions.
T	Transmitters	Transmitters, all types except telephone.
TD	Timing Devices	Mechanical and electronic timing devices, range device, multiplexers, electronic gates, etc.
TF	Transformers	Transformers when used as separate items.
TG	Positioning Devices	Tilt and/or train assemblies.
TK	Tool Kits	Miscellaneous tool assemblies.
TL	Tools	All types except line construction.
TN	Tuning Units	Receiver, transmitter, antenna, tuning units, etc.
TR	Transducers	Magnetic heads, phono pickups, sonar transducers, vibration pickups, etc.

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Table 2.—Component indicators—Continued

Comp. ind.	Family name	Examples of use (not to be construed as limiting the application of the component indicator)
TS	Test Items	Test and measuring equipment not otherwise included; boresighting and alinement equipment.
TV	Tester, Tube	Electronic tube tester.
TW	Tapes and Recording-Wires.	Recording tape and wire, splicing, electrical insulating tape, etc.
U	Connectors, Audio and Power.	Unions, plugs, sockets, adapters, etc.
UG	Connectors, RF	Unions, plugs, sockets, choke couplings, adapters, elbows, flanges, etc.
ZM	Impedance Measuring Devices.	Used for measuring Q, C, L, R or PF, etc.

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APPENDIX II—ELECTRICAL, ELECTRONIC, AND MECHANICAL SYMBOLS

METERS.

A - AMMETER

CRO - OSCILLOSCOPE

G - GALVANOMETER

MA - MILLIAMMETER

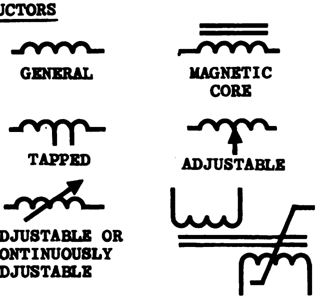
OHM - OHMMETER

V - VOLTMETER

PERMANENT MAGNET

AC SOURCE

INDUCTORS



GENERAL

MAGNETIC CORE

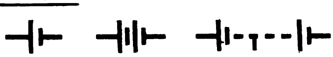
TAPPED

ADJUSTABLE

ADJUSTABLE OR CONTINUOUSLY ADJUSTABLE

SATURABLE CORE REACTOR

BATTERIES



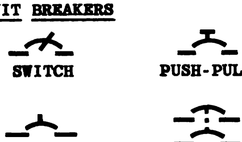
ONE CELL

MULTICELL

TAPPED MULTICELL

(LONG LINE IS ALWAYS POSITIVE)

CIRCUIT BREAKERS



SWITCH

PUSH-PULL

PUSH

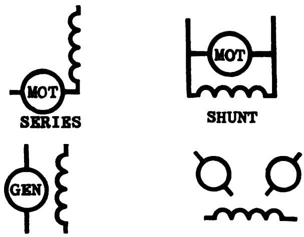
GANGED

MOTORS AND GENERATORS

MOTOR

GENERATOR

TYPES OF WINDINGS



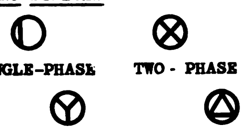
SERIES

SHUNT

SEPARATELY EXCITED

DYNAMOTOR

WINDING SYMBOLS



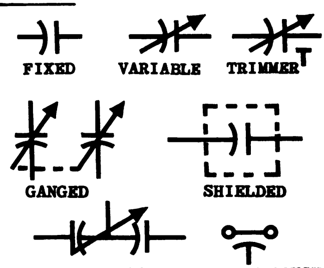
SINGLE-PHASE

TWO - PHASE

THREE-PHASE (WYE)

THREE-PHASE (DELTA)

CAPACITORS



FIXED

VARIABLE

TRIMMER

GANGED

SHIELDED

SPLIT-STATOR

FEED-THROUGH

(WHEN CAPACITOR ELECTRODE IDENTIFICATION IS NECESSARY, THE CURVED ELEMENT SHALL REPRESENT THE OUTSIDE ELECTRODE IN FIXED PAPER-DIELECTRIC AND CERAMIC-DIELECTRIC, THE NEGATIVE ELECTRODE IN ELECTROLYTIC CAPACITORS, THE MOVING ELEMENT IN VARIABLE AND ADJUSTABLE CAPACITORS, AND THE LOW POTENTIAL ELEMENT IN FEED-THROUGH CAPACITORS.)

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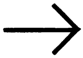
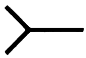
CHASSIS CONNECTION

(THE CHASSIS OR FRAME IS NOT NECESSARILY AT GROUND POTENTIAL.)

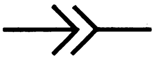
CONNECTORS



MALE
(PIN CONTACT)

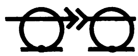


FEMALE
(SOCKET CONTACT)

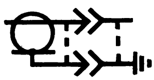


ENGAGED
(PIN-TO-SOCKET)

COAXIAL
(MALE)



COAXIAL CONNECTORS
MATED

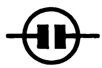


COAXIAL CONNECTED
TO SINGLE CONDUCTOR

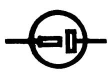
THE CONNECTOR SYMBOL IS NOT AN ARROWHEAD. IT IS LARGER AND THE LINES ARE DRAWN AT A 90° ANGLE.

POWER CONNECTORS

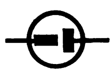
NON POLARIZED,
FEMALE CONTACTS
(2-CONDUCTOR)



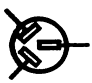
NON POLARIZED,
MALE CONTACTS
(2-CONDUCTOR)



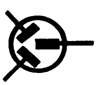
POLARIZED
FEMALE CONTACTS
(2-CONDUCTOR)



POLARIZED
MALE CONTACTS
(2 CONDUCTOR)



POLARIZED
FEMALE CONTACTS
(3-CONDUCTOR)



POLARIZED
MALE CONTACTS
(3-CONDUCTOR)

CRYSTAL UNIT

QUARTZ CRYSTAL; PIEZOELECTRIC CRYSTAL UNIT.

CONTACTS

SWITCH

MOMENTARY
SWITCH

LOCKING

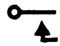
NONLOCKING

 OR  OR 

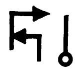
FOR JACK, KEY,
RELAY, ETC.

CONTACT ASSEMBLIES

CLOSED CONTACT
(BREAK)

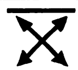


OPEN CONTACT
(MAKE)

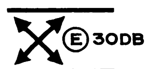


MAKE BEFORE
BREAK

COUPLERS, DIRECTIONAL



GENERAL

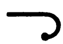


E PLANE APERTURE
COUPLING, 30 DB
TRANSMISSION LOSS

COUPLING

GENERALLY USED FOR COAXIAL AND WAVEGUIDE TRANSMISSION.

COUPLING BY APERTURE WITH AN OPENING OF LESS THAN FULL WAVEGUIDE SIZE. TYPE OF COUPLING WILL BE INDICATED WITHIN CIRCLE (E, H, OR HE).



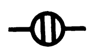
COUPLING BY LOOP TO SPACE

COUPLING BY LOOP TO GUIDED TRANSMISSION PATH

LIGHT, INDICATING

 OR 

INDICATING, PILOT, SIGNALING OR SWITCHBOARD PILOT LIGHT, GENERAL.



JEWELLED INDICATOR OR WARNING LIGHT.

THE LETTER L IS ADDED IN THE SYMBOL TO INDICATE LAMP.

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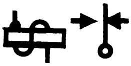
APPENDIX II—Continued

SHIELDING

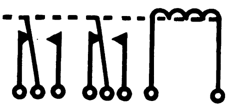
SHORT DASHES.-NORMALLY USED FOR ELECTRIC OR MAGNETIC SHIELDING

RELAYS

RELAY COIL (DOT INDICATES INNER END OF WINDING)



RELAY WITH TRANSFER CONTACTS (SPDT)



DOUBLE POLE, DOUBLE THROW (DPDT) RELAY

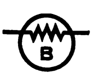
RESISTORS

GENERAL

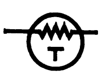
TAPPED

VARIABLE

ADJUSTABLE



THERMAL (BALLAST LAMP)



THERMAL (THERMISTOR)

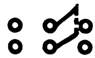
INSTRUMENT OR RELAY SHUNT

SWITCHES

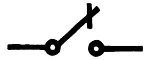
GENERAL (SINGLE THROW)

GENERAL (DOUBLE THROW)

SWITCHES (CONT)

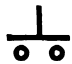


TWO-POLE DOUBLE-THROW SWITCH

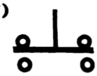


KNIFE SWITCH

PUSH BUTTON (BREAK)

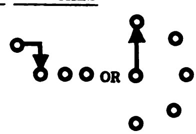


PUSH BUTTON (MAKE)



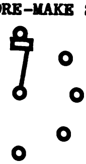
PUSH BUTTON TWO CIRCUIT

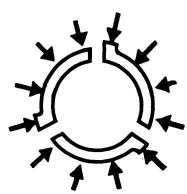
SELECTOR SWITCHES



GENERAL
ANY NUMBER OF TRANSMISSION PATHS MAY BE SHOWN. ALSO BREAK-BEFORE-MAKE SWITCH.

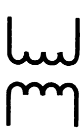
MAKE-BEFORE BREAK





WAFER, TYPICAL 3-POLE, 3-CIRCUIT SWITCH. VIEWED FROM END OPPOSITE CONTROL KNOB. FOR MORE THAN ONE SECTION, #1 IS NEAREST CONTROL KNOB.

TRANSFORMERS



GENERAL

MAGNETIC CORE TRANSFORMER

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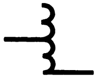
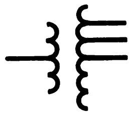
TRANSFORMERS (CONT)



WITH TAPS, SINGLE-PHASE



AUTOTRANSFORMER

SYNCHROS

GENERAL

A LETTER COMBINATION FROM THE FOLLOWING LIST SHALL BE PLACED ADJACENT TO THE SYMBOL TO INDICATE THE TYPE OF SYNCHRO:

- TX - TORQUE TRANSMITTER
- TDX - TORQUE DIFFERENTIAL TRANSMITTER
- CX - CONTROL TRANSMITTER
- CDX - CONTROL DIFFERENTIAL TRANSMITTER
- TR- TORQUE RECEIVER
- CT - CONTROL TRANSFORMER

TRANSMITTER, RECEIVER, OR CONTROL TRANSFORMER

DIFFERENTIAL TRANSMITTER OR RECEIVER

TUBES, ELECTRON

COMPONENT TUBE SYMBOLS

DIRECTLY-HEATED (FILAMENTARY) CATHODE

INDIRECTLY-HEATED CATHODE

GRID

HEATER

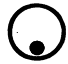
COLD CATHODE

ANODE OR PLATE

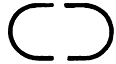
PHOTO CATHODE

ELECTRON TUBES (CONT)

ENVELOPE (SHELL)



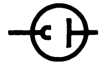
GAS FILLED ENVELOPE



SPLIT ENVELOPE

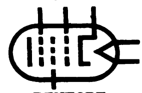
TYPICAL BUILDUP OF TUBE EXAMPLES

COLD CATHODE GAS TUBE

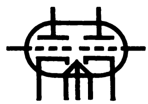


PHOTOTUBE SINGLE UNIT, VACUUM

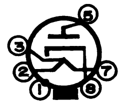
DIODE



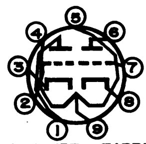
PENTODE



TWIN TRIODE ILLUSTRATING ELONGATED ENVELOPE

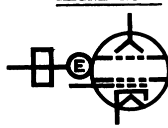


DIODE SHOWING BASE CONNECTIONS



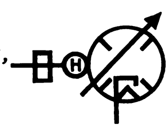
TWIN TRIODE WITH TAPPED HEATER

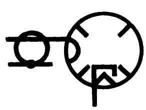
MAGNETRONS AND KLYSTRONS



REFLEX KLYSTRON, APERTURE COUPLED

TUNEABLE MAGNETRON, APERTURE COUPLED





RESONANT TYPE WITH COAXIAL OUTPUT

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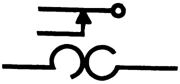
ELEMENT, THERMAL

FLASHER; THERMAL CUTOUT



THERMAL RELAY WITH NORMALLY CLOSED CONTACT.

FUSE

GROUND

PATH, TRANSMISSION

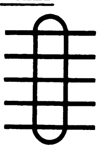
CONDUCTOR OR GROUP OF CONDUCTORS

AIR OR SPACE PATH

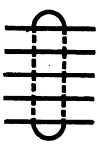
DIEL

DIELECTRIC PATH OTHER THAN AIR

CABLES

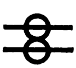


FIVE-CONDUCTOR CABLE



SHIELDED FIVE-CONDUCTOR CABLE

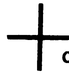
NUMBER OF CONDUCTORS MAY BE ONE OR MORE AS NECESSARY



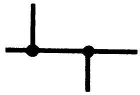
TWISTED PAIR

COAXIAL

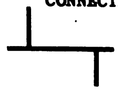
PATH, TRANSMISSION (CONT)



CROSSING NOT CONNECTED

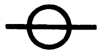


OR

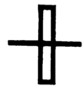


JUNCTION CONNECTED

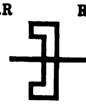
WAVEGUIDES



CIRCULAR

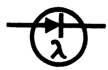


RECTANGULAR

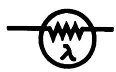


RIDGED

PHOTOELECTRIC CELLS



ASYMMETRICAL PHOTOCONDUCIVE TRANSDUCER (RESISTIVE)



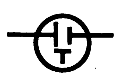
SELENIUM CELL

RECTIFIERS

METALLIC RECTIFIER; ASYMMETRICAL VARISTOR; CRYSTAL DIODE; ELECTROLYTIC RECTIFIER. ARROW SHOWS DIRECTION OF FORWARD (EASY) CURRENT AS INDICATED BY D. C. AMMETER.

THERMOCOUPLES

TEMPERATURE-MEASURING THERMOCOUPLE (DISSIMILAR METAL DEVICE)



TEMPERATURE-MEASURING SEMICONDUCTOR THERMOCOUPLE

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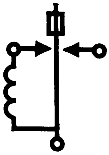
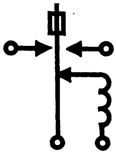
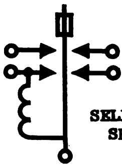
VIBRATORS



TYPICAL, SHUNT DRIVE



TYPICAL, SEPARATE DRIVE



SELF-RECTIFYING SHUNT DRIVE

MECHANICAL SYMBOLS

TUBE AND HOSE LINES

SERVICE	RISER OR STACK	SYMBOL
ENGINE COOLANT	EC	—— E C ——
FUEL SUPPLY	F	—— F ——
LUBRICATING OIL	LO	—— L O ——
OIL BREATHER	OB	—— O B ——
PNEUMATIC	PN	—— PN ——
SELF-SEALING		
VACUUM		——V——
VENT	V	——V——
VENT PRESSURE	PV	——PV——
VENT RETURN	VR	——VR——
DOWN (OR CLOSE)		
EMERGENCY PRESSURE		
HOSE CONNECTION, RIGID TUBING		

HOSE, FLEXIBLE

RETURN

SUPPLY FLUID, PUMP SUCTION

SUCTION GRAVITY

SUPPLY PRESSURE

UP (OR OPEN)

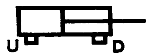
VENT

HYDRAULIC AND PNEUMATIC EQUIPMENT

ACCUMULATOR

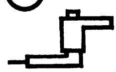
COUPLING, SELF-SEALING

CYLINDER, ACTUATING



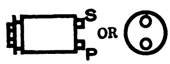
FILTER OR STRAINER

FITTING, SWIVEL

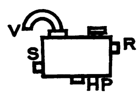


GAGE, PRESSURE

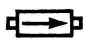
PUMP, POWER DRIVEN



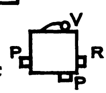
RESERVOIR



VALVE, CHECK, AUTOMATIC



VALVE, PRESSURE REGULATING (UNLOADING) AUTOMATIC



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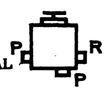
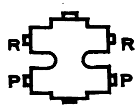


VALVE, RELIEF



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VALVE, RESTRICTOR, BOTH WAYS

VALVE, RESTRICTOR, PARTIAL ONE-WAY

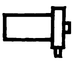
INDICATOR, QUANTITY

MOTOR, PNEUMATIC

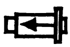
PUMP, AIR

PUMP

FILTER, AIR



VALVE, AIR CHECK

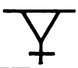


VALVES

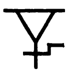
BACK PRESSURE

CROSS FEED

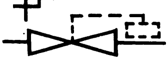
DRAIN



DUMP



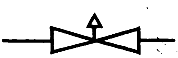
FLOAT OPERATED



GATE

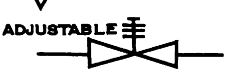
GLOBE

NEEDLE



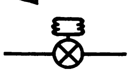
POPPET

PRESSURE REGULATOR



SOLENOID

TEMPERATURE CONTROL

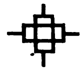


WATER REGULATOR

FITTINGS

BANJO

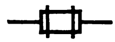
BULKHEAD FITTING



BUSHING

CAP

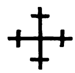
CONNECTOR, HOSE



CONNECTOR, NUT AND SLEEVE

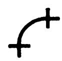
COUPLING, FEMALE

CROSS



ELBOW, 45 DEGREES

ELBOW, 90 DEGREES

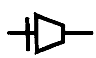


ELBOW, REDUCING

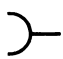
EXPANSION JOINT, BELLOWS

EXPANSION JOINT, SLIDING

FLANGE, REDUCING

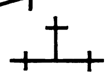


NIPPLE

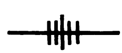


REDUCER, CONCENTRIC

TEE



UNION, FLANGED



UNION, SCREWED

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APPENDIX III

GLOSSARY OF GUIDED MISSILE TERMS

ACCELERATION, LATERAL.—The linear acceleration of a vehicle along the lateral or "Y" axis.

ACCELERATION, LONGITUDINAL.—The linear acceleration of a vehicle parallel to the longitudinal or "X" axis.

ACCELERATION, NORMAL.—The linear acceleration of a vehicle along the normal or "Z" axis.

ACCELERATION, PITCH.—The angular acceleration of a vehicle about its lateral or "Y" axis.

ACCELERATION, ROLL.—The angular acceleration of a vehicle about its longitudinal or "X" axis.

ACCELERATION, YAW.—The angular acceleration of a vehicle about its normal or "Z" axis.

ACCELEROMETER.—An instrument that measures one or more components of the accelerations of a vehicle; a transducer.

ACCUMULATOR, PRESSURE.—An apparatus for storing fluid under pressure, usually consisting of a chamber separated into a gas compartment and a fluid compartment by a diaphragm. Fluid stored in accumulators is used to actuate pressure-operated devices.

ACOUSTIC VELOCITY.—The speed of sound or similar pressure waves.

ACTUATOR.—A hydraulic or pneumatic mechanism (hydraulic or pneumatic servos) which positions the wings or control surfaces in accordance with electrical signals.

AILERON.—A hinged or movable surface on an airframe, the primary function of which is to induce a rolling moment on the airframe.

AIRFOIL.—A thin body, such as a wing, aileron, or rudder, designed to obtain reaction from the air through which it moves.

AIRFRAME.—Concerning guided missiles, the assembled principal structural components, less propulsion system, control and electronic equipment, and payload.

AIR MOTOR.—A rotating device driven by a high-pressure gas source.

ALTIMETER.—An instrument that measures the elevation above a given datum plane.

ALTITUDE, ABSOLUTE.—Altitude with respect to the surface of the earth as differentiated from altitude with respect to sea level. Sometimes referred to as radar or radio altitude.

ALTITUDE, CRITICAL.—In guided missile practice, the maximum altitude at which the propulsion system performs satisfactorily.

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Angle, crab.—The angle between the direction in which a missile is heading and its true course.

Angle, drift.—The horizontal angle between the longitudinal axis of the missile and its path relative to the ground.

Angstrom unit.—The unit of length equal to one ten-thousandth of a micron, or one-hundred millionth of a centimeter. Used to express lengths of extremely short waves, such as infrared waves.

Antenna.—A device, i. e., conductor, horn, dipole, etc., for transmitting or receiving radio waves, exclusive of the means of connecting its main portion with the transmitting or receiving apparatus.

Antenna array.—Designates two or more antennas coupled together in a single mounting, such as to give desired directional characteristics.

Antenna, dipole.—A center-fed antenna which is constructed to be approximately one-half as long as the wavelength it is designed to transmit or receive.

Antenna, dish.—(*See* Dish, radar.)

Antenna gimbals.—The mechanical frame of the intelligence head containing two mutually perpendicular intersecting axes of rotation to which the antenna reflector is attached.

Antenna horn.—The flared end of a radar waveguide which has been matched to the surrounding space for efficient radiation of energy from within the guide to space.

Antenna stabilization gyroscope.—A gyroscope that provides signals to stabilize the antenna in azimuth along the line of sight to the target.

Arming.—As applied to fuzes, the changing from a safe condition to a state of readiness for initiation. Generally a fuze is caused to arm by acceleration, rotation, clock mechanism, or air travel, or by a combination of these.

Athodyd.—A ramjet. An abbreviation for Aero THermODYnamic Duct.

Attenuator.—A device designed to cause a loss in energy in a system without introducing appreciable distortion in the desired frequencies.

Attitude.—The position of a missile as determined by the inclination of its axes to some frame of reference. If not otherwise specified, this frame of reference is fixed to the earth.

Arming delay mechanism.—A device, usually an inertia-operated valve, which prevents operation of the hydraulic or pneumatic servos until the missile is safely clear of the launching aircraft. The fact that an initial maximum deflection of the wings could cause the missile to collide with the aircraft makes the delay necessary.

Automatic pilot.—An automatic control mechanism for keeping a missile level in flight on a set course or for executing desired maneuvers. Sometimes called gyropilot, mechanical pilot, robot pilot, or autopilot.

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AXES OF A MISSILE.—Three fixed lines of reference, usually passing through the center of gravity of the missile and mutually perpendicular. The horizontal axis in the plane of symmetry, usually parallel to the axis of the thrust line of the jet or rocket motor, is called the longitudinal axis; the axis perpendicular to this, in the plane of symmetry, is called the normal or yaw axis; the third axis perpendicular to the other two is called the lateral or pitch axis. In mathematical discussion, the first of these axes, drawn from front to rear is generally designated the "X" axis; the second drawn downward, the "Z" axis; and the third, running from left to right, the "Y" axis.

AZIMUTH.—A direction expressed as a horizontal angle usually in degrees or mils and measured clockwise from north. Thus, azimuth will be true azimuth, grid azimuth, or magnetic azimuth, depending upon which north is used.

BABBLE.—The resulting interference, or cross talk, from a large number of interfering channels.

BACK SCATTERING.—Refers to the scattering of energy of the radar reflected signal.

BANG-BANG.—(*See* Control, bang-bang.)

BANK.—To incline the missile laterally; i. e., to rotate it about its longitudinal axis.

BEAM RIDER.—(*See* Guidance, beam rider.)

BLACK BODY.—A perfect absorber of all radiant energy that falls upon it; does not reflect radiant energy but radiates energy solely as a function of its temperature.

BLOW-OUT DISK.—A mechanism, consisting generally of a thin metal diaphragm, sometimes installed in a rocket motor as a safety measure against excess gas pressure.

BOLOMETER.—(1) A very sensitive type of metallic resistance thermometer, used for measurements of thermal radiation. (*See* Detector, infrared.) (2) In electronics, a small resistive element capable of dissipating microwave power, using the heat so developed to effect a change in its resistance, thus serving as an indicator; commonly used as a detector in low- and medium-level power measuring equipment.

BOOSTER.—(1) A high-explosive element sufficiently sensitive to be actuated by a small explosive element in a fuze and powerful enough to cause detonation of the main explosive charge. (2) An auxiliary propulsion system which travels with the missile and which may or may not separate from the missile when its impulse has been delivered.

BRENNSCHLUSS.—In rockets, the time at which burning ceases. (German)

BURN OUT.—(1) To overheat a combustion chamber or nozzle to such

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an extent that the walls weaken and rupture. (2) The time at which a jet motor ceases to burn. (*See* Brennschluss.)

CANARD.—A type of airframe construction having the stabilizing and control surfaces forward of the main supporting surfaces.

CARDAN-MOUNTED.—Gimbal mounted.

CEILING, ABSOLUTE.—The maximum height above sea level at which a given aircraft or missile would be able to maintain horizontal flight under standard air conditions.

CENTER OF GRAVITY.—(*See* Center of mass.)

CENTER OF MASS.—The point at which all mass of a body may be regarded as being concentrated, so far as motion of translation is concerned. Commonly called center of gravity.

CHANNEL, TELEMETER.—Designates the complete route for transmission of a telemetered function, including pickup, commutator, modulator, transmitter, receiver, demodulator, decoder, and recorder.

COMBUSTOR.—A name generally assigned to the combination of flame holder, igniter, combustion chamber, and injection system of a ramjet.

COMPONENT.—A major section or assembly unit of a missile; such as the warhead, fuze, control section, the motor, etc. Also an integral subassembly or replaceable plug-in unit of a major section, such as a servo amplifier, summing amplifier, or guidance receiver.

COMPUTER.—A mechanism which performs mathematical computations.

COMPUTER ANALOGUE.—A computer in which quantities and relationships are represented by continuously variable physical quantities such that approximate solutions can be obtained readily.

COMPUTER, DIGITAL.—A computer in which quantities are represented in numerical form and which generally is made to solve complex mathematical problems by repetitive use of the fundamental processes of addition, subtraction, multiplication, and division.

CONFIGURATION.—The relative distribution or arrangement of parts in a structure.

CONICAL SCANNING.—Defines a radar scanning system wherein a point on the radar beam describes a circle at the base of a cone, and the axis is the generatrix of the cone.

CONTROL.—(1) Concerning missiles in general, the entire processes of intelligence and maneuver intended for reaching a specified destination, with special connotation on changes in course owing to data which may be observed and computed either in the missile or externally. (2) Concerning the airframe, a device for effecting a change in motion.

CONTROL, BANG-BANG.—A control system used in guidance, wherein the corrective control applied to the missile is always applied to the full extent of the servo motion.

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CONTROL, PROPORTIONAL.—Control in which the action to correct an error is made proportional to the error.

CONTROL SECTION.—Consists of the electromechanical portions of a missile, with the exceptions of the fuze, warhead, motor, wings, and fins.

CONTROL SURFACE.—A movable airfoil designed to be rotated or otherwise moved by a control servomechanism in order to change the attitude of the aircraft or missile.

CRAB-ANGLE.—(*See* Angle, crab.)

CRUCIFORM.—A configuration in the form of a cross with equal legs, 90° apart.

DAMPING.—The reduction or elimination of oscillation in a system by the introduction of friction or some other type of loss into the system.

DECCA NAVIGATION.—(*See* Navigation, hyperbolic.)

DECIBEL.—A unit for expressing the magnitude of a change in sound or electrical power level.

DEFLAGRATION.—(*See* Detonation.)

DELTA WING.—A triangular-shaped, low-aspect-ratio airfoil with tapered leading edge and straight trailing edge.

DESTRUCTOR.—An explosive or other device for intentionally destroying a missile or aircraft, or a component thereof.

DETECTOR, INFRARED.—Thermal devices for observing and measuring infrared radiation, such as the bolometer, radiomicrometer, thermopile, pneumatic cell, photocell, photographic plate, and photoconductive cell.

DETONATION.—A sudden and violent explosion. Detonation is practically instantaneous. The slower burning of some explosives is called deflagration.

DETONATION, LOW-ORDER.—A partial or slow explosion. As applied to military explosives, generally caused by accidental or inadequate initiation.

DETONATOR.—An explosive device, sensitive to electrical or mechanical impulse. Generally used to set off a larger quantity of explosive.

DIFFUSER.—A duct of varying cross section designed to convert a high-speed gas into low-speed flow at an increased pressure.

DISH, RADAR.—The parabolic reflector which is part of certain radar systems.

DITHER.—A signal of controlled amplitude and frequency applied to the servomotor operating a transfer valve, such that the transfer valve is constantly being "quivered" and cannot stick in its null position.

DOPPLER EFFECT.—The apparent change in frequency of sound or radio waves, reaching an observer or a radio receiver, caused by a

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change in distance or range between the source and observer or the receiver during the interval of reception.

DOUBLE-BASE POWDER.—Propellant containing nitrocellulose and another principal explosive ingredient.

DOUBLE TAPER.—Taper of an airfoil in planform and in cross-section thickness from root to tip.

DOUBLE WEDGE.—A diamond-shaped cross section.

DOUBLE-WEDGE, MODIFIED.—Diamond-shaped cross section with flat parallel upper and lower surfaces making a six-sided shape.

ELEVATOR.—A movable auxiliary airfoil, the function of which is to impress a pitching moment on the aircraft. It is usually hinged to the stabilizer.

ELEVONS.—Wing flaps combining the functions of ELEVators and ailerONS.

END INSTRUMENT.—(*See* Pickup.)

ENERGY.—Work, or its equivalent, in any form.

ENERGY, CHEMICAL.—Energy obtained from oxidation or other chemical reaction.

ENERGY, KINETIC.—A capacity of a body for doing work by virtue of its motion. Quantitatively, it is one-half the mass times the velocity squared.

ENERGY, POTENTIAL.—The capacity of a body for doing work by virtue of its position or distortion.

ENERGY, RADIANT.—Energy consisting of electromagnetic waves, such as light, infrared, radio, and radar.

ERROR SIGNAL.—(1) In servomechanisms, the signal, frequently a voltage, applied to the control circuit that indicates misalinement between the controlling and controlled members. (2) In tracking systems, a voltage, depending upon the signal received from the target, whose sign and magnitude depend on the angle between the target and the center of the scanning beam.

EXPLOSIVE TRAIN.—That portion of a fuze or fuze system consisting of explosive components, such as primer, detonator, booster, etc., necessary to cause functioning of a warhead or destructor.

FAIRING.—An auxiliary member or structure whose primary function is to reduce the drag of the part to which it is attached.

FIN.—A fixed or adjustable airfoil attached to a missile or aircraft approximately parallel to the plane of symmetry to afford directional stability.

FLAP.—A hinged or pivoted airfoil forming the rear portion of an airfoil used to vary the effective camber.

FLAPERONS.—Control surfaces, integrally or differentially operated in

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some missiles, which combine the braking effect and increased lift from the flaps with the roll control of the ailerons.

FLIGHT PATH.—The path of the center of gravity of a missile with reference to the earth or with reference to a coordinate frame fixed relative to the missile.

FREQUENCY, INFRARED.—The range of invisible radiation frequencies which adjoins the visible red spectrum and extends to microwave radio frequencies.

FREQUENCY, SUBCARRIER.—In telemetering, an intermediate frequency that is modulated by intelligence signals, and in turn is used to modulate the radio carrier either alone or in conjunction with subcarriers of other channels.

FUSELAGE.—The body of approximately streamline form, to which the wings and tail unit of an aircraft or missiles are attached.

FUZE.—A device designed to initiate a detonation under the conditions desired, such as by impact, elapsed time, proximity, or command.

GEE NAVIGATION.—(*See* Navigation, hyperbolic.)

GENERATOR, GAS.—A solid propellant which produces large quantities of hot gases when ignited, the energy of which is used to operate pneumatic devices.

GIMBAL.—A mechanical frame containing two mutually perpendicular intersecting axes of rotation.

GLIDE BOMB.—A winged missile powered by gravity.

GRAY BODY.—An imperfect "black body."

GROUP.—In telemetering, designates a number of subcarrier oscillators.

GUIDANCE.—Concerning missiles, the entire process of intelligence and of maneuver intended for reaching a specified destination, with special connotation on the flight path and on information for determining the proper course.

GUIDANCE, BEAM RIDER.—A system for guiding missiles which utilizes a beam directed into space, such that the center of the beam forms a line along which it is desired to direct the missile. The beam, which may be fixed either in elevation or azimuth (or it may be moving), may be especially a radar beam, a light beam, or a beam of some other type. Equipment is built into the missile such that the missile can determine when it is in the center of the beam or can determine the direction and magnitude of the error when it has deviated from the center of the beam. Also built into the missile are suitable electronic circuits, servomotors, aerodynamic surfaces, and/or other equipment, such that the missile, by its own initiative, will return toward the center of the beam when it has deviated therefrom for any reason.

GUIDANCE, COMMAND.—A guidance system wherein intelligence transmitted to the missile from an outside source causes the missile to traverse a directed path in space.

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GUIDANCE, HOMING.—A system by which a missile steers itself toward a target by means of a self-contained mechanism which is activated by some distinguishing characteristic of the target.

GUIDANCE, HOMING, ACTIVE.—A system of homing guidance wherein both the source for illuminating the target and the receiver are carried within the missile.

GUIDANCE, HOMING, PASSIVE.—A system of homing guidance wherein the receiver in the missile utilizes natural radiations from the target.

GUIDANCE, HOMING, SEMIACTIVE.—A system of homing guidance wherein the receiver in the missile utilizes radiations from the target which has been illuminated from a source other than in the missile.

GUIDANCE, INERTIAL.—A system independent of information obtained from outside the missile, the sensitive elements of which system make use of Newton's second law of motion.

GUIDANCE, MIDCOURSE.—The guidance applied to a missile between termination of the launching phase and the start of the terminal phase of guidance.

GUIDANCE, PRESET.—A technique of missile control wherein a predetermined path is set into the control mechanism of the vehicle prior to launching and cannot be adjusted after launching.

GUIDANCE, STELLAR.—(*See* Navigation, celestial.)

GUIDANCE, TERMINAL.—The guidance applied to a missile between the termination of the midcourse guidance and impact with or detonation in close proximity of the target.

GUIDANCE, TERRESTRIAL REFERENCE.—A technique of missile control wherein the predetermined path set into the control system of a missile can be followed by a device in the missile which reacts to some property of the earth, such as magnetic or gravitational effects.

GUIDED MISSILE.—An unmanned vehicle moving above the earth's surface, whose trajectory or flight path is capable of being altered by a mechanism within the vehicle.

GYROSCOPE.—A wheel or disk, mounted to spin rapidly about an axis and also free to rotate about one or both of two axes perpendicular to each other and to the axis of spin.

GYROSCOPE, DIRECTIONAL.—A gyroscopic instrument for indicating direction, containing a free gyroscope which holds its position in azimuth and thus indicates angular deviation from a set course.

GYROSCOPE, FREE.—A gyroscope mounted with two or more gimbal rings so that its spin axis is free to maintain a fixed orientation in space.

GYROSCOPE, RATE.—A gyroscope with a single gimbal mounting, such that rotation about an axis perpendicular to the axis of the gimbal and to the axis of the gyro produces a precessional torque proportional to the rate of rotation.

HOMING.—(*See* Guidance, homing.)

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Hunting.—A condition of instability resulting from overcorrecting by a control device and resultant fluctuation in the quantity intended to be kept constant.

Hydraulic motor.—(*See* Motor, hydraulic.)

Hygroscopic.—Descriptive of a material which readily absorbs and retains moisture.

Hypergolic.—Capable of igniting spontaneously upon contact.

Hypersonic.—(*See* Sonic, hyper (hypersonic).)

Igniter.—A device used to initiate burning of a fuel mixture or a propellant in a ramjet or rocket combustion chamber.

Impulse, specific.—(*See* Specific impulse.)

Impulse, total.—In jet propulsion usage, the product of the average thrust (in pounds) developed by the motor times the burning time (in seconds).

Inertia.—The property of any material to resist change in its state of motion. (*See also* Moment of inertia.)

Ion.—An electrically charged particle formed when one or more electrons are gained or lost by either a neutral atom or a group of atoms. An ion is positive when it has lost electrons, and negative when it has gained electrons.

Ionosphere.—That portion of the earth's atmosphere, beginning about 50 miles above the earth's surface, which consists of layers of highly ionized air capable of bending or reflecting certain radio waves back to earth.

Jato.—An auxiliary rocket device for applying thrust to some structure or apparatus.

Jet.—The exhaust stream or rapid flow of fluid from a small opening or nozzle.

Jet horsepower.—The power of the exhaust jet equal to the product of the thrust and effective jet velocity.

Jet motor.—A motor which provides a forward propulsive force by producing a rearward jet of matter.

Launcher.—A mechanical structure which constrains a missile to move in the desired direction of flight during initial motion but does not itself propel the missile.

Launcher, finite length.—A launcher which supports the missile in the desired attitude prior to ignition, and which exercises control on the direction of the missile's travel after ignition.

Launcher, zero length.—A launcher which supports the missile in the desired attitude prior to ignition, and which exercises no control on the direction of the missile's direction after ignition.

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Lead prediction.—The act of directing a missile ahead of a moving target—leading in aim—to a predicted collision point.

Leading edge.—The foremost edge of an airfoil.

Linear.—A linear relationship exists between two quantities when the change in one quantity is exactly proportional to the change in the other quantity.

Local speed of sound.—The velocity of propagation of acoustic waves over a small region as determined by the conditions there.

Mach number.—The ratio of the velocity of a body to that of sound in the medium being considered. Thus, at sea level, in air, a body moving at a Mach number of one ($M=1$) would have a velocity of 1,116.2 ft/sec.

Mass ratio.—As applied to rockets, the ratio of the total propellant weight to the gross rocket weight.

Mil.—(1) A unit of angular measurement. In guided missile usage, a mil equals 1/6400th of a circle. (2) A unit of linear measurement equal to 0.001 inch.

Modification.—A major or minor change in the design of an adopted item of material which is effected in order to correct a deficiency, facilitate production, or to improve operational effectiveness.

Moment of force.—The effectiveness of a force to produce a rotation about an axis. It is measured by the product of the force and the perpendicular distance from the line of action of the force to the axis of rotation. Also known as torque.

Moment of inertia.—A measure of resistance offered by a body to angular acceleration; the product of mass and distance squared from the axis of reference, over all particles in the system or body.

Momentum—The product of the mass of a body and its linear velocity.

Momentum, angular.—The product of the angular velocity, and the moment of inertia of a body. Also called moment of momentum.

Monocoque.—A type of fuselage relying for its rigidity upon the surface or skin, which may be of sheet metal or layers of veneer.

Motor, hydraulic.—A rotating device driven by a high-pressure hydraulic fluid.

Navigation, celestial.—Navigation by means of observations of celestial bodies. A system wherein a missile, suitably instrumented and containing all necessary guidance equipment, may follow a predetermined course in space with reference primarily to the relative positions of the missile and certain preselected celestial bodies. Determination of the vertical to the earth's surface may be necessary in addition.

Navigation, hyperbolic.—A general method for determining the lines of position by measuring the difference in distance of the navigator

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or navigating apparatus from two or more stations of known position. The difference in distance is determined by measuring the difference in time of arrival of signals transmitted from two or more stations. Although a great variety of signaling methods are theoretically possible, only radio waves are now commonly used in hyperbolic navigation. One system using continuous wave signals is known as DECCA. LORAN and GEE are systems using signals transmitted as pulses.

NUTATION.—The oscillation of the axis of a rotating body. In radar, the familiar situation where the radar reflector is stationary, the center of the dipole, which has its longitudinal axis fixed, is caused to describe a circle centered at the focus of the paraboloid and lying in a plane perpendicular to the axis of the paraboloid.

OGIVE.—A shape familiar on the nose of projectiles; the surface of revolution generated by rotating the line segment and the arc of a circle about an axis parallel to the line.

PARAMETER.—A quantity which may have various values each fixed within the limits of a stated case or discussion.

PAYLOAD.—Warhead, fuze, and container. In the case of research and test vehicles, this includes equipment for taking data and transmitting or recovering it.

PICKUP.—In telemetering, a sensing instrument to measure a varying quantity, such as a pressure gage, strain gage element, position indicator, accelerometer, etc.; also called an end instrument.

PITCH.—An angular displacement about an axis parallel to the lateral axis of an airframe.

PITCH INDICATOR.—An instrument for indicating the existence and approximate magnitude of the angular velocity about the lateral axis of an airframe.

PRECESSION.—A change in the orientation of the axis of a rotating body, such as a spinning projectile or gyroscope, the effect of which is to rotate this axis (axis of spin) about a line (axis of precession) perpendicular to its original direction and to the axis (axis of torque) of the moment producing that force.

PRESSURE.—Force per unit of area.

PROPELLANT.—Material consisting of fuel and oxidizer, either separate or together in a mixture or compound which, if suitably ignited, changes into a large volume of hot gases capable of propelling a rocket or other projectile.

PULSE JET.—A compressorless jet-propulsion device which produces thrust intermittently with an operating frequency determined by the acoustic resonance of the engine.

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Radome.—A contraction of the words RAdar DOME. The housing for a radar antenna, transparent to radio-frequency energy.

Ramjet.—A compressorless jet-propulsion device which depends for its operation on the air compression accomplished by the forward motion of the unit.

Resojet.—(*See* Pulse jet.)

Resolution.—In radar, the minimum separation in angle or in range between two targets which the equipment is capable of distinguishing.

Rocket.—A thrust-producing system or a complete missile which derives its thrust from ejection of hot gases generated from material carried in the system, not requiring intake of air or water.

Roll.—An angular displacement about an axis parallel to the longitudinal axis of an airframe.

Rudder.—A hinged or movable auxiliary airfoil on an aircraft, the function of which is to impress a yawing moment on the airframe.

Scan, axis of.—In a scanning system, the axis about which information as to the target location is collected and with reference to which target displacement is measured.

Scan, radar.—Denotes the motion of a radio-frequency beam through space in searching for a target. There are many types of scanning used which are denoted by the path described in space by a point on the radar beam, such as circular, spiral, and helical.

Scanning, electrical.—A type of scanning which is accomplished electrically and without motion of the antenna.

Seeker, target.—A homing guidance device. (*See* Guidance, homing.)

Self-destruction equipment.—Some type of explosive in a circuit such that it can be exploded by (1) a time-delay mechanism, (2) a radio-command link, (3) an automatic trip mechanism, or other signal.

Servo link.—A power amplifier, usually mechanical, by which signals at a low power level are made to operate control surfaces requiring relatively large power inputs.

Servo system.—A closed-cycle automatic-control system so designed that the output element or output quantity follows as closely as desired the input to the system. The output is caused to follow the input by the action of the servo controller upon the output element in such a way as to cause the instantaneous error, or difference, between the output and input to approach zero. All servo systems are dynamic systems containing at least one feedback loop which provides an input signal proportional to the deviation of the actual output from the desired output; this property distinguishes servo systems from ordinary automatic-control systems. In general, servomechanisms exhibit the following properties: (1) include power

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amplification, (2) are "error sensitive" in operation, and (3) are capable of following rapid variations of input.

SIGNAL.—Any waveform or variation thereof with time serving to convey the desired intelligence in communication.

SIMULATOR.—Concerning missiles, a device which solves a problem by use of components which obey the same equations as the system being studied. A simulator is an alternative means of determining the effects of changing each of several design parameters at much less expense than building and testing complete missiles or systems.

SKIDDING.—Sliding sidewise away from the center of curvature when turning. It is caused by banking insufficiently and is the opposite of sideslipping.

SKID FIN.—A longitudinal vertical surface, usually placed above the upper wing to increase the lateral stability.

SONIC, HYPER (HYPERSONIC).—High velocities of the order of M–5 or greater.

SONIC SPEED.—The speed of sound.

SONIC, SUB (SUBSONIC).—Less than the speed of sound or less than a Mach number of one.

SONIC, SUPER (SUPERSONIC).—Faster than the speed of sound.

SONIC, TRAN (TRANSONIC).—The intermediate speed in which the flow pattern changes from subsonic to supersonic.

SPECIFIC GRAVITY.—The ratio of the weight of any volume of water to the weight of an equal volume of water at 4° C.

SPECIFIC IMPULSE.—Pounds of thrust developed per pound of propellants consumed per second, or the ratio of thrust to propellant mass flow.

SPECIFIC THRUST.—The ratio between the thrust of a jet reaction motor and the total propellant flow rate producing the thrust.

SQUIB.—A small pyrotechnic device which may be used to fire the igniter in a rocket or for some similar purpose. Not to be confused with a detonator which explodes.

STABILITY.—The property of a system which causes it, when its equilibrium is disturbed, to develop forces or moments tending to restore the original condition.

STABILIZER.—Concerning aircraft, any airfoil whose primary function is to increase the stability of an aircraft. It usually refers to the fixed horizontal tail surface of an aircraft as distinguished from the fixed vertical surface.

STEADY STATE.—The condition of a system which is essentially constant, after damping out of initial transients or fluctuations.

STRATOSPHERE.—The region of upper atmosphere characterized by little or no temperature change with a change in altitude. The stratosphere is separated from the lower atmosphere, or troposphere, by the tropopause.

SUBSTAINER.—A propulsion system, which travels with, and does not

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separate from, the missile. Usually applied to solid propellant rocket motors when used as the principal propulsion system as distinguished from an auxiliary motor or booster.

SYNCHRO.—The universal term applied to any of the various synchronous devices.

TAB.—An auxiliary airfoil attached to a control surface for the purpose of reducing the control force or trimming the aircraft or missile.

TAIL SURFACE.—A stabilizing or control surface in the tail of an aircraft.

TARGET, RADAR.—Any reflecting object of particular interest in the path of a radar beam.

TELEMETERING SYSTEM.—The complete measuring, transmitting, and receiving apparatus for remotely indicating, recording, and/or integrating information.

TEMPERATURE.—Degree of hotness or coldness measured on a definite scale.

TEMPERATURE, ABSOLUTE.—Scales based upon zero degrees as the lowest temperature attainable even theoretically. Absolute zero is approximately $-273.16°$ C. or $-459.7°$ F.

TEMPERATURE, CENTIGRADE (C.).—A temperature scale divided into 100 degrees, in which the freezing point of water is 0° and the boiling point is 100°.

TEMPERATURE, FAHRENHEIT (F.).—A temperature scale in which the freezing point of water is 32° and the boiling point is 212°.

TEMPERATURE, KELVIN (K. OR T.).—An absolute temperature scale, assumed to be a measure of kinetic energy, in which $1°$ K. $= 1°$ C. and the freezing point of water is approximately 273.16° K.

TEMPERATURE, RANKINE (R.).—A thermometer scale based on absolute zero of the Fahrenheit scale, in which the freezing and boiling point of water are separated by 180°. The freezing point of water is approximately 492° R.

THEODOLITE.—An optical instrument for measuring horizontal and vertical angles with precision.

THERMISTOR.—A contraction of THERMal resISTOR. A resistor whose value varies with temperature in a definite desired manner. Used in circuits to compensate for temperature variations in other parts, to measure temperatures, or as a nonlinear circuit element.

THERMOCOUPLE.—A pair of dissimiliar conductors in contact, forming a thermojunction which when heated develops a potential difference between the parts; used for measuring temperature differences.

THERMOJET.—Air-duct type engine in which air is scooped from surrounding atmosphere, compressed, heated by combustion, and then expanded and discharged at high velocity.

THERMOPILE.—An instrument consisting of several thermocouples so

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arranged as to give, when heated, a multiplied thermoelectric current; often used for detecting very slight variations in temperature.

THROAT.—In rocket and jet engines, the most restricted part of an exhaust nozzle.

THRUST.—The resultant force in the direction of motion, owing to components of the pressure forces in excess of ambient atmospheric pressure, acting on all inner surfaces of the vehicle parallel to the direction of motion. Thrust less drag equals accelerating force.

TRACKING, AUTOMATIC.—The process of utilizing range data and/or angular data in such a manner as to obtain error signals which are then used to drive devices that keep the tracking system locked on the target.

TRAILING EDGE.—The rearmost edge of an airfoil.

TRANSDUCER.—A device which converts the energy of one transmission system into the energy of another transmission system.

TRANSISTOR.—A common designation for germanium triode, consisting of two fine wires imbedded at the proper spacing into a matrix of germanium, the whole exhibiting many properties of a three-element vacuum tube.

TRANSONIC.—(*See* Sonic, tran.)

TRIM.—(1) In electronics, denotes a small change or necessary adjustment of the tuning capacity. (2) Concerning aircraft, the attitude with respect to wind axes at which balance occurs in rectilinear flight with free controls.

TROPOPAUSE.—The boundary or zone of transition between the troposphere and the stratosphere. Its height is variable; it is highest about 17–18 km. over the equator, the lowest, about 6–8 km. over the poles. Its height also changes with the seasons and with the passage of cyclones and anticyclones.

TROPOSPHERE.—The region of the atmosphere extending from the surface of the earth up to the tropopause; characterized by convective air currents and a pronounced vertical temperature gradient, in contrast to the convectionless and almost vertically isothermal stratosphere above the tropopause.

TUMBLING.—(1) The act performed by a two-frame gyroscope when both frames become coplanar. Under these circumstances, the gyro wheel rotates about a diameter as well as about its polar axis, resulting in loss of control. (2) Concerning missiles and projectiles in flight, turning end-over-end about the transverse missile axis.

TURBOJET.—A jet motor whose air is supplied by a turbine-driven compressor; the turbine being activated by exhaust gases from the motor.

ULTRAVIOLET.—Electromagnetic radiation extending from the visible spectrum at the violet end up to the region of low-frequency X-rays, with wavelengths from about 136 to 4,000 Angstrom units.

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UMBILICAL CORD.—A cable fitted with a quick-disconnect plug at the missile end, through which missile equipment is controlled and tested while the missile is still attached to launching equipment or parent plane.

VARISTOR.—A special type of resistor which varies considerably with temperature; useful in making temperature measurements or in compensating circuits for other temperature effects.

VISCOSITY.—The resistance to shear in a fluid.

WARHEAD.—The portion of a missile intended to be lethal or incapacitating; normally the warhead casing, explosive, and/or chemical or incendiary agents, etc.

WING.—A general term applied to a major airfoil.

YAW.—An angular displacement about an axis parallel to the normal axis of an aircraft or missile.

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APPENDIX IV

ANSWERS TO QUIZZES

CHAPTER 1

GUIDED MISSILES AND THE GF RATING

1. d.
2. c.
3. a.
4. d.
5. c.
6. d.
7. c.
8. b.
9. c.
10. a.
11. b.
12. c.
13. c.
14. d.
15. d.
16. a.
17. d.
18. d.

CHAPTER 2

COMPONENTS OF GUIDED MISSILES

1. b.
2. c.
3. d.
4. d.
5. c.
6. a.
7. c.
8. d.
9. b.
10. c.
11. d.
12. b.
13. a.
14. b.
15. b.
16. d.
17. b.
18. c.
19. a.
20. b.
21. d.
22. a.
23. d.
24. c.
25. b.
26. d.
27. d.
28. a.
29. d.
30. b.
31. b.
32. a.
33. c.
34. c.
35. a.
36. b.
37. c.
38. d.
39. d.
40. b.

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CHAPTER 3

FACTORS AFFECTING MISSILE FLIGHT

1. c.
2. d.
3. c.
4. b.
5. b.
6. c.
7. b.
8. b.
9. c.
10. b.
11. b.
12. d.
13. a.
14. b.
15. a.
16. d.
17. b.
18. d.
19. d.

CHAPTER 4

AIR-LAUNCHED GUIDANCE EQUIPMENT

1. a.
2. b.
3. d.
4. c.
5. b.
6. a.
7. c.
8. d.
9. b.
10. a.
11. d.
12. b.
13. c.
14. d.
15. c.
16. c.
17. d.
18. a.
19. d.
20. a.

CHAPTER 5

BEAM-RIDER AND COMMAND GUIDANCE SYSTEMS

1. b.
2. a.
3. b.
4. d.
5. a.
6. d.
7. c.
8. b.
9. d.
10. b.
11. c.
12. b.
13. a.
14. c.
15. c.
16. b.
17. a.
18. c.
19. b.
20. d.
21. a.
22. c.
23. d.
24. a.
25. d.
26. c.
27. b.
28. c.
29. d.
30. b.
31. d.
32. c.

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CHAPTER 6

HOMING SYSTEMS FOR AIR-LAUNCHED MISSILES

1. b.
2. a.
3. c.
4. a.
5. d.
6. c.
7. d.
8. d.
9. a.
10. a.
11. c.
12. c.
13. b.
14. a.
15. b.
16. b.
17. c.
18. d.
19. a.
20. c.
21. a.
22. c.
23. c.
24. b.
25. b.

CHAPTER 7

INTRODUCTION TO MISSILE CONTROL SYSTEMS

1. b.
2. c.
3. d.
4. b.
5. d.
6. c.
7. c.
8. a.
9. d.
10. d.

CHAPTER 8

BASIC MISSILE CONTROL EQUIPMENT

1. c.
2. d.
3. a.
4. c.
5. c.
6. d.
7. b.
8. d.
9. b.
10. b.
11. a.
12. b.
13. d.
14. c.
15. a.
16. c.
17. d.
18. c.
19. a.
20. b.
21. a.
22. c.
23. c.
24. d.

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CHAPTER 9

MISSILE HYDRAULIC AND PNEUMATIC SYSTEMS

1. c.
2. a.
3. d.
4. c.
5. a.
6. a.
7. b.
8. b.
9. d.
10. c.
11. a.
12. b.
13. a.
14. b.
15. c.
16. c.
17. d.
18. a.
19. b.
20. c.
21. d.
22. d.
23. a.
24. b.

CHAPTER 10

ELECTRICAL POWER SUPPLIES FOR GUIDED MISSILES

1. b.
2. a.
3. c.
4. d.
5. b.
6. c.
7. a.
8. d.
9. a.
10. b.
11. c.
12. d.
13. a.
14. b.
15. c.
16. d.
17. a.
18. b.
19. c.
20. a.
21. b.
22. a.
23. c.
24. b.
25. d.

CHAPTER 11

INTRODUCTION TO MISSILE TELEMETERING

1. a.
2. b.
3. c.
4. b.
5. c.
6. d.
7. b.
8. a.
9. b.
10. d.
11. a.
12. b.
13. a.
14. c.
15. a.
16. a.
17. b.
18. a.
19. d.
20. a.
21. a.
22. c.
23. a.
24. a.
25. c.
26. a.
27. b.
28. c.
29. b.
30. a.

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CHAPTER 12

MISSILE HANDLING AND TESTING

1. d.	10. c.	19. c.
2. a.	11. a.	20. a.
3. c.	12. c.	21. b.
4. b.	13. b.	22. a.
5. c.	14. b.	23. b.
6. c.	15. a.	24. c.
7. a.	16. d.	25. b.
8. d.	17. a.	26. d.
9. a.	18. d.	

CHAPTER 13

MAINTENANCE AND REPAIR PROCEDURES

1. d.	11. c.	21. b.
2. d.	12. c.	22. c.
3. c.	13. b.	23. d.
4. c.	14. b.	24. a.
5. b.	15. a.	25. b.
6. b.	16. a.	26. c.
7. a.	17. d.	27. d.
8. a.	18. c.	28. c.
9. d.	19. b.	29. b.
10. d.	20. a.	30. a.

CHAPTER 14

SAFETY PRECAUTIONS AND FIRST AID

1. c.	8. c.	15. c.
2. b.	9. d.	16. b.
3. c.	10. d.	17. b.
4. c.	11. d.	18. c.
5. b.	12. a.	19. d.
6. b.	13. b.	20. a.
7. b.	14. d.	

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APPENDIX V

QUALIFICATIONS FOR ADVANCEMENT IN RATING

AVIATION GUIDED MISSILEMEN (GF)

(Through Change 10)

General Service Rating

Scope

Aviation Guided Missilemen assemble, test, aline, adjust, replace, and repair internal components of air-launched missiles, excluding propulsion systems and ordnance items and hydraulic/pneumatic systems not associated with missile internal guidance and control; operate, test, adjust, aline, calibrate, and repair missile test equipment; supervise and train personnel in testing and repair of guided missile sections and components and associated test equipment; maintain logs and equipment histories.

Emergency Service Rating

Same as General Service Rating.

Navy Enlisted Classification Codes

For specific Navy enlisted classification codes included within this rating, see *Manual of Navy Enlisted Classification*, NavPers 15105 (Revised), codes GF–7800 through GF–7899.

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Qualifications for advancement in rating	Applicable rates GF
100 PRACTICAL FACTORS	
101 OPERATIONAL	
1. Demonstrate under simulated conditions the rescue of a person in contact with an energized electrical circuit, resuscitation of a person unconscious from electrical shock, and treatment for electrical burns	3
2. Handle, stow, and secure missile sections and components, excluding ordnance and propulsion equipment, on own ship or station; replace desiccant and recharge containers, if required for equipment	3
3. Unpack and prepare missile sections and components for assembly; visually inspect connections, fittings, and mating surfaces for proper condition; clean and prepare mating surfaces	3
4. Assemble and disassemble missile sections as member of team, on own ship or station; aline and secure sections; install and remove wings and control surfaces; connect or disconnect fittings, if required for missile	3
5. Prepare missile and associated test equipment for missile system test by making proper connections, setting missile and test equipment switches, installing required measuring devices, and setting missile and components in proper location	3
6. Operate specialized missile test equipment under direct supervision; take and verify dial readings; vary signals and switch positions as directed	3
7. Secure missile and associated missile test equipment after missile system test; set all switches, knobs, and valves for shutting down test; bleed pressurized lines; disconnect all electrical, hydraulic, or pneumatic lines; remove measuring devices mounted on missile for test	3
8. Demonstrate knowledge of electrical, ordnance (solid-propellent rocket motors, high-explosive warheads, fuzes, igniters), fueling, high-pressure air, hydraulic, jet engine, and mechanical safety precautions	3

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Qualifications for advancement in rating	*Applicable rates* GF
101 OPERATIONAL—Continued	
9. Charge missile internal guidance and control pressurized systems; prepare missile for charging by removing access plates and making required hose connections; charge missile system following check list instructions; use hand tools, charging unit, or air supply system	2
102 MAINTENANCE AND/OR REPAIR	
1. Select and use hand tools and small portable power tools necessary for assembly and replacement of parts in air-launched missiles	3
2. Make electrical connections and splices including soldered joints	3
3. Operate the following test equipment:	
a. Voltmeter	3
b. Ammeter	3
c. Ohmmeter	3
d. Multimeter	3
e. Megger	3
f. Tube tester	3
g. Battery tester	3
4. Locate and identify major components and subassemblies by reference to block diagrams and mechanical drawings	3
5. Draw and interpret schematic diagrams of electrical circuits; read and interpret wiring diagrams found in technical maintenance publications; identify electronic and mechanical symbols	3
6. Lubricate missile and missile test equipment in accordance with handbook instructions, on own ship or station	3
7. Perform tests on batteries for missile or missile test equipment; replace weak or faulty batteries	3
8. Clean commutators and commutator heads; replace brushes on missile and missile test equipment rotating electrical machinery such as dynamotor, motor, generator; replace dynamotors, generators, and motors	3
9. Identify capacitors, resistors, and wiring by standard color code systems	3

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Qualifications for advancement in rating	Applicable rates GF
102 MAINTENANCE AND/OR REPAIR—Continued	
10. Perform tests for short circuits, grounds, and continuity on missile and missile test equipment electrical circuits. Visually inspect for loose, damaged, broken, or burned components	3
11. Replace fuses, wiring, switches, plugs, jacks, and relays on electrical equipment; make connections	3
12. Replace identified or isolated vacuum tubes and circuit components, electronic packages, relays, potentiometers, multielement plugs and jacks; clean contacts, terminal pins, and plugs; make solder connections	3
13. Perform tests for short circuits, grounds, and continuity on missile and missile test equipment electronic circuits; adjust potentiometers and controls; substitute components	2
14. Operate the following test equipment:	
a. Oscilloscope	2
b. Signal generator	2
c. Frequency meter	2
d. Vacuum tube voltmeter	2
15. Draw and interpret schematic diagrams of electronic circuits; read and interpret wiring diagrams of electronic circuits found in technical maintenance publications	2
16. Effect changes to electronic circuits in accordance with wiring diagrams or field change instructions	2
17. Perform calibration and adjustments of missile-borne telemetering equipment on own ship or stations	2
18. Perform and supervise all tests for short circuits, grounds, and continuity on missile and missile test equipment electrical circuits; visually inspect for loose, damaged, broken, or burned components and repair or replace as required	2
19. Perform casualty analysis of malfunctioning hydraulic or pneumatic missile systems; locate leaks; visually inspect for damage; adjust fittings and movements and free bound parts; effect replacement or substitution of parts; retest system for proper operation	2

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Qualifications for advancement in rating	*Applicable rates* GF
102 MAINTENANCE AND/OR REPAIR—Continued	
20. Determine missile axes and angles of incidence; set trim tabs; use clinometers, gages, protractors, or jigs, as required	2
21. Perform functional tests on missile system; direct and coordinate operation of specialized test equipment; observe motion of control surfaces and/or dial readings; adjust, aline, and calibrate components within allowable tolerances; reject malfunctioning missiles or sections	2
22. Trace signals through electronic circuits, using an oscilloscope; determine and compare waveforms with established or standard forms	2
23. Calibrate tachometer generators on own ship or station; direct and coordinate operation of test and calibration equipment	2
24. Perform missile component tests; isolate and locate malfunctioning components; check test equipment for proper operation; coordinate and direct test equipment operators; replace or repair defective equipment excluding tender/yard maintenance; determine signal inputs for measuring component responses	1
25. Operate the following test equipment:	
a. Spectrum analyzer	1
b. Pulse generator	1
c. Sweep generator	1
d. Impedance bridge	1
e. Resistance bridge	1
f. RF wattmeter	1
26. Perform casualty analysis of malfunctioning electromechanical, electrohydraulic, or electropneumatic systems including servo systems; disassemble units and make adjustments, replacements, or repairs excluding tender/yard maintenance	1
27. Perform casualty analysis of malfunctioning electronic power supplies and regulators; isolate, locate, and replace electronic components, assemblies, subassemblies, and detailed parts	1

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Qualifications for advancement in rating	Applicable rates GF
102 MAINTENANCE AND/OR REPAIR—Continued	
28. Perform casualty analysis of free and rate gyroscopes, gyro control and autopilot systems; trace malfunctions from test data information by testing associated mechanical and electrical components for proper operation; check for proper gyro output signal; observe caging and erecting mechanism for proper operation; aline synchros to electrical zero; aline a servo indicating or setting system; replace malfunctioning gyroscopes	1
29. Perform delicate balancing and adjustment and alinement tests on electronic and electrical circuits and test equipment components; reduce data and make corrections; compare values, set predetermined values and check responses	C
30. Analyze graphic recorder records	C
31. Perform casualty analysis of malfunctioning missile and missile test equipment systems and components; effect allowable repairs	C
32. Perform casualty analysis of malfunctioning missile-borne telemetering components on own ship or station; analyze graphic recorder signals; calibrate and test frequency and proper operation of channels; isolate inoperative channels by making station checks; replace components which cannot be tuned within allowable limits	C
103 ADMINISTRATIVE AND/OR CLERICAL	
1. Maintain required shop and equipment work logs; log work accomplished; record test data	3
2. Maintain electronic equipment histories; prepare job orders, work requisitions, and failure reports	2
3. Supervise unpacking, handling, and stowage of missiles and missile components, excluding ordnance equipment; direct movement of missile, missile sections, and components in transporting, placing on test stand, assembly rack, and stowage racks	2
4. Inspect work performed in preparation of missile and associated test equipment for missile system tests for optimum operation of equipment	2
5. Supervise and instruct personnel in charging pressurized systems, replacement of parts and components, performance of missile functional and systems tests, and circuit repairs	1

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Qualifications for advancement in rating	Applicable rates GF
103 ADMINISTRATIVE AND/OR CLERICAL—Continued	
6. Inspect work performed in maintenance and repair of missile guidance, control, and telemetering systems; inspect for proper test and adjustment procedures to insure optimum operation of equipment	1
7. Determine quantities and obtain part and stock numbers from technical and supply publications for tools, spare equipment, and replacement parts; requisition, store, and account for materials and spare parts	1
8. Supervise and instruct personnel in all guided missile safety precautions	C
9. Supervise and instruct personnel in performance of missile system and component tests	C
10. Inspect work performed in maintenance and repair of electronic power supplies and regulators and electrohydraulic or electropneumatic systems included in missile internal guidance and control	C
11. Organize work assignments and supervise personnel to accomplish maintenance projects as directed	C
12. Organize and maintain technical library of missile publications and other data required by technical bureau concerned	C
13. Evaluate completed equipment check lists, shop and equipment work logs, equipment histories and equipment failure reports; review stub requisitions for spare parts, tools, and materials	C
14. Prepare reports covering condition and status of missiles and associated equipment	C
15. Conduct and evaluate inventories of missiles, associated material, tools, and test equipment	C
200 EXAMINATION SUBJECTS	
201 OPERATIONAL	
1. Safety precautions to be observed in working with or near explosive ordnance, electrical, fueling, high-pressure air, hydraulic, and mechanical equipment	3
2. Effects of electrical shock, method of resuscitation of a person unconscious from electrical shock; treatment for electrical burns	3
3. Types and purposes of common tools used in assembly and disassembly of missile sections and missile containers	3

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Qualifications for advancement in rating		Applicable rates GF
201	OPERATIONAL—Continued	
	4. Purpose and application of desiccants in missile stowage; interpretation of desiccant colors	3
	5. Types of missile guidance, stabilization, and propulsion systems	3
202	MAINTENANCE AND/OR REPAIR	
	1. Types, structures, maintenance procedures, and electrical characteristics of batteries used in missiles and missile test equipment	3
	2. Methods of cleaning commutators and commutator heads and precautions to be observed	3
	3. Identification of standard electronic parts symbols used in schematic drawings	3
	4. Types of information shown and meanings of electrical and mechanical symbols used in schematic diagrams of missile equipment	3
	5. Identification of parts using electromechanical assembly drawings	3
	6. Electrical and physical characteristics of electric motors, generators, and dynamotors	3
	7. Soldering materials and soldering methods used in maintenance and repair	3
	8. Methods and equipment used in electrical tests for continuity, grounds, and short circuits	3
	9. Applications of laws of magnetism to d-c motors and generators	3
	10. Meaning of:	
	a. Conductors and insulators	3
	b. Lines of force	3
	c. Field intensity	3
	d. Flux density	3
	e. Permeability	3
	f. Ampere-turns	3
	g. Hysteresis and eddy currents	3
	h. Self and mutual induction	3
	i. Electromagnetic induction	3
	j. Coulomb	3
	k. Volt	3
	l. Ampere	3
	m. Ohm	3
	n. Henry	3
	o. Circular mil	3

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Qualifications for advancement in rating	Applicable rates GF
202 MAINTENANCE AND/OR REPAIR—Continued	
p. Farad	3
q. Watt	3
r. Kilowatt	3
s. Power factor	3
t. Kilovolt-amperes	3
u. Reactance	3
v. Capacitance	3
w. Inductance	3
x. Impedance	3
y. Torque	3
z. Frequency	3
aa. Cycle	3
bb. Phase	3
11. Function of following measuring devices in electrical circuits:	
a. Ohmmeters	3
b. Meggers	3
c. Ammeters (a-c and d-c)	3
d. Voltmeters (a-c and d-c)	3
e. Frequency meters	3
f. Wheatstone bridge	3
g. Thermocouple instruments	3
12. Function of the following in hydraulic and pneumatic systems:	
a. Pneumatic gages	3
b. Check valves	3
c. Reducing valves	3
d. Safety valves	3
e. Restrictors	3
f. Actuators	3
g. Gaskets	3
h. O–rings	3
i. Manifolds	3
j. Pressure regulators	3
k. Flow regulators	3
l. Micronic filters	3
m. Servo valves	3

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Qualifications for advancement in rating	Applicable rates GF
202 MAINTENANCE AND/OR REPAIR—Continued	
13. Function of the following in electrical circuits:	
a. Resistors	3
b. Rheostats and potentiometers	3
c. Solenoids	3
d. Inductors	3
e. Capacitors	3
f. Fuses	3
g. Switches	3
h. Transformers	3
i. Relays	3
j. Copper oxide rectifiers	3
k. Selenium rectifiers	3
14. RMA color coding systems for capacitors and resistors	3
15. Relationship of length and cross-sectional area to resistance of a conductor	3
16. Relationship of temperature, pressure, and volume in gases	3
17. Relationship of resistance, temperature, and current in an electrical conductor	3
18. Calculate current, voltage, and resistance in d-c series and parallel circuits containing not more than four elements	3
19. Relationship of resistance, inductance, and capacitance in a-c circuits	3
20. Relationship of current, voltage, and impedance in a-c circuits	3
21. Theory of permanent-magnet moving-coil meters with knowledge of shunts and of multiplier resistors	3
22. Current, voltage, and impedance relationships in series and parallel resonant circuits	2
23. Calculate current, voltage, phase angle, impedance, and resonance in a-c series and parallel circuits containing not more than a combination of four elements	2
24. Effects of meter sensitivity in circuit voltage measurement	2
25. Types and purpose of gas-filled tubes and cathode ray tubes; and function of each of their elements	2
26. Purpose and function of diode, dry disk, and crystal rectifiers; purpose and function of triode, tetrode, and pentode vacuum tubes and function of each of their elements	2

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Qualifications for advancement in rating	Applicable rates GF
202 MAINTENANCE AND/OR REPAIR—Continued	
27. Function of oscilloscope, tube tester, electronic voltmeter, signal generator, frequency meter, spectrum analyzer, pulse generator, impedance bridge, resistance bridge, RF wattmeter, and FM signal generator	2
28. Function and operating characteristics of missile pneumatic systems and components	2
29. Function and operating characteristics of missile hydraulic systems and components	2
30. Function and operating principles of check valves and solenoid-operated valves in missile hydraulic and pneumatic systems	2
31. Function and operating principles of pressure regulators in missile hydraulic and pneumatic systems	2
32. Methods of adjusting flow and pressure regulators used in missile hydraulic and pneumatic systems	2
33. Function and operating principles of gear and piston type pumps used in missile hydraulic systems	2
34. Function and operating principles of solenoid-operated hydraulic actuators used in missile aerodynamic control systems	2
35. Proper method of locating casualties by localizing to main unit, subassembly, circuit, and component	1
36. Proper method of making RF power measurements	1
37. Methods of coupling: Transformer, impedance, capacitance, resistive, direct, and tuned; purpose for and methods of achieving impedance matching in circuits	1
38. Function of half-wave, full-wave, and bridge-type rectifiers and voltage doublers; simple voltage regulators and gaseous-type regulator tubes; function of capacitor and choke input filters	1
39. Applications of low-pass, high-pass, and band-pass filters	1
40. Operating principles of diode, dry disk, and crystal rectifiers	1
41. Operating principles of half-wave, full-wave, and bridge-type rectifiers and voltage doublers; simple voltage regulators and gaseous-type regulator tubes	1
42. Functions and applications of servomechanisms and synchros as applied to missiles and missile test equipment	1

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Qualifications for advancement in rating	Applicable rates GF
202 MAINTENANCE AND/OR REPAIR—Continued	
43. Methods of making gain, phase, balancing, and zeroing adjustments to servo loops found in missile internal guidance and stabilization systems	1
44. Function and physical and electrical characteristics of free and rate gyroscopes including caging and erecting devices	1
45. Function of the following:	
a. Audio amplifiers	1
b. RF amplifiers	1
c. Video amplifiers	1
d. Cathode followers	1
e. Oscillators: Hartley, crystal-controlled, Colpitts, TPTG, electron-coupled	1
f. Diode and crystal detectors	1
g. Modulators	1
h. AGC circuits	1
i. AFC circuits	1
j. Discriminators	1
k. Phase shifters	1
l. Differentiators	1
m. Integrators	1
n. Trigger circuits and multivibrators	1
o. Coincidence circuits	1
p. Limiters	1
q. Clippers	1
r. Peakers	1
s. Clampers	1
t. Counting circuits	1
u. Sawtooth generators	1
v. Wire and coaxial transmission lines and waveguides	1
w. T/R and AT/R tubes	1
x. Klystrons	1
y. Magnetrons	1
z. Crystal mixers	1
aa. Photoelectric cells	1
46. Electrical characteristics of Hertz, Marconi, and dipole antennas. Principles of operation of dish reflectors and of parasitic reflectors and directors	C
47. Operating principles of modulation: Amplitude, frequency, phase, and pulse	C
48. Operating principles of those circuits or elements listed in item 202–45	C

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	Qualifications for advancement in rating	Applicable rates GF
203	ADMINISTRATIVE AND/OR CLERICAL	
	1. System of assigning "AN" letter-number combinations as designation for electronic equipment	3
	2. Application of allowance lists in determining spare parts, tools, and supplies kept on board	1
	3. Procedures for obtaining replacement parts and supplies; maintenance of inventory	1
300	PATH OF ADVANCEMENT TO WARRANT OFFICER AND LIMITED DUTY OFFICER	
	Aviation Guided Missilemen advance to Warrant Aviation Ordnance Technician and/or to Limited Duty Officer, Aviation Ordnance. As an alternate, Aviation Guided Missilemen advance to Warrant Aviation Electronics Technician and/or to Limited Duty Officer, Aviation Electronics.	

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